SUNNYSIDE GOLD CORPORATION
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March 18, 1993

RECEIVED
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Division of Minerals & Geology

Mr. James Stevens
Colorado Department of Natural Resources
Division of Minerals and Geology
1313 Sherman Street, Room 423
Denver, CO 80203-2273

RE: File No. M-77-378
San Juan County
Technical Revision (TR 14) Submittal
American Tunnel and Terry Tunnel Hydraulic Seals

Dear Mr. Stevens:

This letter is a Technical Revision submittal to provide bulkhead designs to replace the conceptual plan (Appendix 2-F Consolidated Permit (112) Application for the Sunnyside Mine and Mill) presently in the MLR permit. These designs were prepared by John F. Abel, Jr. a Colorado P.E., who has had previous experience with water impounding tunnel bulkheads. Attached is a paper co-authored by him titled **Tunnel Bulkheads for Acid Mine Drainage.** The submitted bulkhead designs are similar.

DISCUSSION:

A comparison of the conceptual plan in the permit and this TR is presented below.

Goal

The conceptual plan submitted in 1987 proposes to place plain concrete plugs in the American Tunnel and Terry Tunnel. These plugs are to be placed back in the tunnels far enough so that additional hydrostatic pressure would have limited effect on the overburden rock. The goal is to accumulate water within the underground workings until equilibrium conditions prevail. The sealed mine conditions will provide water of better quality than what is produced (without seals) from tunnel discharges. This impounded water would conceivably enter the near surface joint/fracture system(s) associated with the mine.

Goal - Cont

The proposed goal is to install tunnel bulkheads to impound groundwater within the Sunnyside Mine in order to eliminate flow from the Sunnyside Mine property to surface down the tunnels, to restore an approximation of pre-Sunnyside Mine hydrologic conditions and eliminate the need for perpetual water treatment. The conceptual plan does not address the fact that Sunnyside Gold Corporation only has an easement for usage of the American Tunnel and does not own the portal or land the tunnel passes through thereby the right to plug the portal is highly questionable. This was discussed in our 6/26/92 meeting. In addition, near portal plugs would not be below the near surface fracture system. Any plugs in this zone would not impound water within the underground workings to allow an approximation of pre-mine hydrologic conditions. It would just by-pass the plug through the fracture system in the portal area and not improve in quality by producing a flooded or reducing atmosphere within the mine. The proposed site location close to the Sunnyside Gold property line will more nearly produce the goal stated in the conceptual plan for waters originating from Sunnyside Gold property. No action is proposed for the American Tunnel not owned by Sunnyside Gold or water originating from this section of tunnel.

Location

The conceptual plan is vague other than specifying that ground cover will be adequate to prevent hydrofracturing. There are only two plugs identified.

This plan identifies four sites requiring plugs to effectively block all mine related pathways to the surface between the American Tunnel Level (10,580') and the Lake Emma drainage ditch (12,210'). The F-Level and B-Level Brenneman plugs will be located along drift connections to the Brenneman/Mogul Mine and eventually to surface. The Terry Tunnel plug will be approximately 3800 feet from the portal and the American Tunnel plug will be approximately 7950 feet from the portal. All sites were selected based on the following:

1) Suitable site locations were based on rock competency, lack of faulting, tightness (ie. lack of seepage), roughness (to provide suitable shear resistance) and size.

2) The closest suitable site to the main Sunnyside Mine workings was selected in each case. This will maximize high resistance flow path distances to surface and provide additional overburden cover to provide additional protection against hydrofracturing.

Location - Cont

In addition, the American Tunnel bulkhead site was selected to be as close to the Sunnyside Mine property line as suitable site locations would allow. As discussed under Goals above, Sunnyside Gold Corporation only has an easement for usage of the tunnel and does not own the portal or land the tunnel passes through. The site selected is ideal in that a considerable distance (greater than 1000 feet) towards the portal is dry. This will make verification of the effects of the impounded water on flows from non-Sunnyside Gold property in the American Tunnel relatively certain.

Design

The conceptual plan proposes unreinforced concrete plug design with the maximum possible head for design loading. Design details were not addressed.

The attached **Bulkhead Design for the Sunnyside Mine** by John F. Abel, Jr. contains the proposed bulkhead designs. It is consistent with the conceptual plan, the major difference being reinforced concrete plugs with low pressure contact grouting are proposed instead of unreinforced plugs. The parameter difference between the conceptual and proposed design calculation for the American Tunnel plug is because of plug site location and topographic map selection for Lake Emma elevation verses actual outlet survey elevation.

This design was prepared using ACI Building Code Requirements because of its conservatism. Quantifiable factors of safety built into the ACI code are shown in Table 1. of the design report. They range from 1.57 to 1.77 for the bulkheads. Another ACI design requirement that is not quantifiable until after completion of the project but builds conservatism into the design is the mix design requirement for 4990 psi strength while using a design strength of 3000 psi.
Other prudent design assumptions that probably increase the factor of safety providing worst case conditions do not occur are:

1) Assumption of simple beam loading for flexural stress.
2) Providing two-way reinforcement while assuming one-way for design.
3) Assuming maximum possible head determined by topographical limits.

Design - Cont

4) Ignoring bond strength between the rock and the concrete.
5) Assuming worst case orientation for earthquake loading for all bulkheads.
6) Providing additional shear studs on the by-pass pipe.
7) Ignoring shear resistance provided by the flanges and couplings to resist the design thrust on the installed pipes.

For additional conservatism Sunnyside Gold Corporation will also do the following items not addressed in the design report.

1) The Brenneman B-Level and Brenneman F-Level bulkheads are above the existing water table so tightness (ie water seeping fractures) could not be evaluated. In addition, neither site will be accessible after water impoundment is started for inspection and/or remedial work. To compensate, two identical bulkheads (built according to the submitted design) will be constructed 100-200 feet apart. This will provide additional assurance that leakage will not occur along these pathways.

2) A limestone barrier from floor to roof will be constructed on the water side of each bulkhead. While this is probably not needed, given the sulfate resistant mix and the neutral or mildly acidic nature of the mine water that will contact the bulkheads, it is added protection for the bulkhead.

Monitoring

The conceptual plan does not address monitoring but pressure monitoring pipes will be installed through the accessible bulkheads (Terry Tunnel and American Tunnel) to track head gain behind the bulkheads. Seepage conditions will also be monitored at these sites. The Terry Tunnel pressure and seepage conditions can only be monitored during summer because of access but by monitoring the American Tunnel pressure, head conditions at the Terry Tunnel will be known. It is conceivable that within six (6) months of pipe closure, field confirmed evaluations/predictions could be made concerning the success of the plugs and subsequent permanent closure (ie. pipe grouting, surface reclamation) time schedules could be set and/or implemented.

RECLAMATION PLAN:

Surface reclamation plans are not affected by this TR. Time schedules for implementing surface reclamation plans will vary from those in the permit. Surface reclamation at the American Tunnel and Terry Tunnel (ie. water treatment facilities) is scheduled to be concurrent with plug placement. These facilities cannot be reclaimed until the plugs are proven to be effective and the Colorado Department of Health amends the American Tunnel CDPS discharge point location as discussed in their November 20, 1992 letter copied to you.

If you have any questions concerning this submittal, please contact me. Attached is a check for $150.00 to cover the fee for review of this TR.

Sincerely,

Larry Perino

Larry Perino
Superintendent-Technical Services

cc: John C. Kubic, CDH, WQCD/w enclosures
David C. Naccarati, Echo Bay Management

LP/cjm

JOHN F. ABEL, JR.
MINING ENGINEER

MAR 22 1993

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BULKHEAD DESIGN
FOR THE
SUNNYSIDE MINE

Sunnyside Gold Corp., An Echo Bay Company

Report to

Sunnyside Gold Corp.
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by

John F. Abel, Jr.
Mining Engineer
Colorado P.E. 5642

John F. Abel, Jr.

March 10, 1993

TABLE OF CONTENTS

EXECUTIVE SUMMARY

This report contains designs for the four reinforced concrete bulkheads needed to impound the water currently passing through the Sunnyside Mine workings. The purpose of these bulkheads is to restore the pre-mining hydrology as best as possible to that present prior to mining. The bulkheads will prevent surface and ground water entering the Sunnyside Mine from moving through the low resistance mining developed flow paths, as is currently the situation. The four bulkheads will impound water in the mine, the water that is flowing through low resistance paths presented by mine workings. After completing bulkhead construction, impounded water will only be able to exit the Sunnyside Mine through either natural groundwater channels or at the maximum elevation of the mine pool, the 12210-foot elevation of the Lake Emma out-flow drainage ditch, or a variable combination of both.

Impoundment of water within the Sunnyside Mine workings will significantly reduce the oxidation rate of sulfide minerals presently exposed to air in abandoned stopes, drifts and tunnels. Oxidation of metallic sulfides produces the metallic and sulfate ion contamination of the water draining from the Sunnyside Mine through the Terry Tunnel and the American Tunnel. The only oxygen available to oxidize sulfide minerals below the mine pool water level will be that dissolved in the water. Obviously, the oxygen content of even fully oxygen saturated water is lower than in air. Once the oxygen in the impounded water is depleted it can only be replaced by water circulation to the mine pool surface. Once the bulkheads are closed, differential rock temperature should be the only energy source available to replenish depleted oxygen below the surface of the mine pool. This extremely low energy source will be resisted by the restricted and complicated potential flow paths within the mine. Careful design and construction of the bulkheads is essential because bulkhead leakage would serve as a gravity driven source of oxygen for sulfide mineral oxidation.

The bulkhead locations were chosen to maximize the length of natural hydraulic flow paths and to minimize the potential for water leakage through the jointed rock adjacent to the bulkheads. Table 1 presents the geometric conditions at the four selected bulkhead locations. The factors of safety listed in Table 1 are for the critical flexural bending stress. These factors of safety are in relation to American Concrete Institute's (ACI) Building Code Requirements for Reinforced Concrete (ACI 318-89). The critical deep-beam, i.e. the bulkheads, flexural stresses will be resisted by two-way, horizontal and vertical, rebar reinforcement. The ACI code (Section 9.2.1) requires the design strength for a dead or fluid loaded reinforced concrete deep-beam structure to support 1.4 times the maximum dead or fluid load. In addition, the ACI code requires a strength reduction factor for reinforced concrete in flexure of 0.90 (Section 9.3.2.1). This results in a minimum actual factor of safety of 1.56 against flexure. In the case of shear, ACI requires a strength reduction factor of 0.85 (Section 9.3.2.3). The actual minimum factor of safety against shear is 1.65.

Table 1. Sunnyside Mine bulkhead design conditions and flexural factors of safety

Bulkhead Tunnel Ident.	Design Head feet (psi)	Bulkhead Design Length feet	Rebar Reinforcement Size	Spacing in.	Design Factor of Safety	Actual Factor of Safety
American Tunnel 13 x 13 ft	1550 (670)	25	#10	7	1.01	1.57
F-Level Terry Tunnel 11 x 11 ft	650 (280)	8	#10	7	1.03	1.60
F-Level Brenneman/ Sunnyside Connection, 10 x 10 ft	630 (270)	8	#10	9	1.01	1.57
B-Level Brenneman/ Sunnyside Connection, 9 x 9 ft	70 (30)	3	#6	12	1.14	1.77

The bulkhead designs include shrinkage and temperature steel for all water-side bulkhead faces. In all cases the shrinkage and temperature steel is two-way, horizontal and vertical, #6 bars on 12-inch centers, in accordance with ACI 318-89, Section 7.12.2.2.

The basic concrete mix is 1:2.5:3.5, cement, sand, aggregate. A water-cement ratio of 0.45 is recommended for the sulfate resistant Type V cement, 5.4 bags per yd^3, to provide maximum sulfate resistance (ACI 318-89, Section 4.2.1). This high sand content mix is recommended to enhance pumpability and to minimize voids and "honey combing" of the placed concrete. Easily pumpable concrete is required because it will not be possible to vibrate the concrete into the bulkhead forms. Fly ash (pozzolan) in the amount of 16 percent of the weight of the cement is recommended to further improve pumpability, increase slump and decrease permeability (Troxell et al, 1968). The Standard Handbook for Civil Engineers (Merritt, 1983, Table 8-4) indicates that a maximum aggregate size of 2 inches can be used. However, it is recommended that 3/4-inch maximum aggregate size be used, again to enhance pumpability and minimize voids, segregation and "honey combing". The mean concrete strength, f'_{CR}, used in determining the proportions of aggregate, cement and water is 4990 psi (ACI 318-89, Sections 5.3.2.2 and Merritt, 1983, p 5-5). This, f'_{CR}, should yield a concrete strength of 3000 psi, or higher, under actual working conditions. This high mean strength is necessary in the absence of compression test cylinder data. It should be possible to adjust the mix proportions when compression test data becomes available.

The planned bulkhead placement sequence is from the highest to the lowest, from the uppermost B-Level Brenneman/Sunnyside connection bulkhead down to the lowest American Tunnel bulkhead. Bulkheading the Terry Tunnel will temporarily transfer additional mine drainage water to the American Tunnel. The anticipated maximum water quantity that would have to pass through the American Tunnel bulkhead during spring runoff is 2200 gpm (4.9 cfs). The nominal 12-inch diameter pipe specified will pass 2500 gpm (5.6 cfs), with 5-foot of head behind the upstream coffer dam. During the planned construction period the anticipated maximum flow through the temporary diversion pipe should be 1200 gpm (2.7 cfs).

The thrust on the diversion pipe will be resisted by headed anchor shear studs (1/2-inch diameter by 2-inch headed studs), welded to the pipe. Two studs are recommended every foot along the pipe, alternating 90 degrees of rotation along the pipe. This design provides 46 studs to resist the thrust when the full 1550 feet of potential head is applied. This provides a design factor of safety of 1.60 and ignores skin friction between the pipe and the concrete and the shear strength of the pipe flanges.

Single continuous bars are specified for all curtain steel. However, splicing can be employed if sufficient lap is provided to develop full bar strength in tension. The overlap development length recommended for the #10 bars is 82 inches. This means, in effect, that each overlapped bar would have to be 41 inches longer and weigh approximately 15 lbs more than a single bar or 30 lbs

more steel per splice with #10 bars. A single #10 bar for the American Tunnel bulkhead weighs only 56 lbs. For the #6 bars a 48 inch development length is recommended. For the #4 bars a 32 inch development length is recommended.

The acceleration from the "maximum credible earthquake" for the Sunnyside Mine area was conservatively applied to all bulkhead orientations and checked against ACI code requirements for earthquake loading. All design bulkheads exceed ACI code requirements.

INTRODUCTION

The bulkhead designs contained in this report have been conservatively prepared. Conservatism was necessary because of the safety and environmental implications of a bulkhead failure, the long life required for the bulkheads and the ultimate inaccessibility of the bulkheads. The American Concrete Institute's "Building Code Requirements for Reinforced Concrete (ACI 318-89)" was utilized because the bulkheads are analogous to reinforced deep-beam concrete structures and because of the inherent conservatism of the code. The deep-beam bulkhead was further, conservatively assumed to act only one-way, between the walls, ribsides, of the tunnel. However, two-way reinforcing steel is provided in the design to transfer the load to the roof and floor. The one-way design assumption in effect produces a factor of safety of two, provided the more difficult roof and floor contacts between the bulkhead concrete and the rock is achieved. The blasted irregularities along the tunnel roof, walls and floor effectively key a bulkhead to the adjacent rock. The American Tunnel calculations are presented in Appendix A.

The U.S. Bureau of Reclamation's manual for the "Design of Small Dams" (USBR, 1977) was not utilized because only one of the three failure criteria for dam stability is even remotely involved in bulkhead design, namely, sliding on the base of the dam. The other two criteria, overturning of the dam and piping of water through and erosion of the foundation material under the dam are not pertinent to bulkheads. The driving force tending to move a dam is the hydraulic thrust against the dam face. The sliding of a mass concrete dam is resisted by the weight of dam and the coefficient of friction between the concrete and the rock on which the dam sits. Kvapil (1965) reports coefficients of surface friction between concrete and granite ranging from 0.70 to 0.90. If the bulkhead were simply sitting on the rock floor of the tunnel, frictional resistance of the approximate 320 ton reinforced concrete bulkhead planned for the American Tunnel would not prevent the bulkhead from being pushed down the tunnel by the over 8100 tons of design hydraulic thrust applied to the water-side of the bulkhead. The irregular blasted surface of the tunnels and the intimate contact between the concrete bulkheads and the rock roof, walls and floor of the tunnels permit a bulkhead to resist the applied thrust. The only way a bulkhead can fail in shear is by shearing through intact concrete or rock, not frictional sliding.

The poorly defined, but low, bond strength between the rock and the concrete was conservatively ignored in the calculations.

The optimum solution to drainage of water containing metallic and sulfate ions from the Sunnyside Mine, or any other mine, is to fill the entire mine with an impermeable backfill. Complete backfilling, if possible, would come the closest to restoring original groundwater conditions. Backfilling would eliminate the low resistance groundwater flow paths presented by the mine workings. Such a solution can neither be accomplished safely nor practically because many of the mine openings are no longer accessible. The volume of even the accessible mine openings renders even incomplete backfilling uneconomic.

Impoundment of water in the Sunnyside Mine behind bulkheads can be equally effective as backfilling in preventing contaminated mine drainage from re-entering the surface water system. The bulkheads were carefully located and designed to eliminate leakage around the bulkheads, to prevent the development of uncontrolled releases of contaminated mine water to the ground surface along natural flow paths and to assure that the bulkheads will remain stable and effective. The essentially stagnant mine pool that will be developed at the Sunnyside Mine is designed to maintain the mine pool below the elevation that will potentially force contaminated water through any known natural fracture system to reenter the surface water system.

This report presents the purpose of the bulkhead system, the design criteria and the individual bulkhead designs.

PURPOSE

A single bulkhead can be used to close a single low resistance groundwater flow path, the tunnel, and eliminate that mine controlled discharge point. The Sunnyside Mine is unique in that four bulkheads have the potential to raise the mine depressed groundwater level 1550 feet, to the 12210-foot elevation of the Lake Emma drainage ditch outflow. These four bulkheads are designed to isolate the Sunnyside Mine from all potential drainage paths to the ground surface below the Lake Emma outflow and reestablish the pre-mining groundwater conditions below the Lake Emma outflow. The Sunnyside Mine bulkhead based mine drainage control system is designed to prevent groundwater that enters the natural near-surface fracture system below Lake Emma from migrating into the mine workings. The pressure of the impounded water should resist movement of groundwater into the Sunnyside Mine.

If, or when, the water level in the Sunnyside Mine reaches its maximum 12210-foot elevation, stable ground water equilibrium with respect to the mine should be established. After that time, major groundwater movement, below the Lake Emma outflow should be the same as the pre-mining surface fracture controlled groundwater system. On the other hand, leakage of water impounded in the mine to the natural fracture system may balance the inflow rate before

the elevation of the mine pool reaches the Lake Emma outflow elevation. In this case a dynamic seasonal mine pool elevation will result.

In either case, water entering the natural surface fracture system during spring runoff should be stored primarily within the natural fracture system. Annual mine pool water level fluctuations will give a rough indication of the natural fracture connection between the mine and the surface water drainage system. Water entering the mine will raise the elevation of the mine pool increasing the hydraulic head resistance to more water entering. Later, during the dry season, water stored in the fracture system and in the case of a fluctuating mine pool elevation a portion of the mine pool, will reenter the surface drainage system. Any stream flow contamination occurring after closure of the bulkheads and equilibrium impoundment of water within the Sunnyside Mine should primarily be from near-surface natural in-fracture oxidation of metallic sulfides, the same process that was taking place prior to mining.

DESIGN CRITERIA

The four bulkhead locations were selected to maximize the distance that water impounded in the mine would have to flow along the high-resistance natural fracture system to reach the ground surface. These locations were also selected to avoid major faults which could potentially provide a natural path for impounded water to exit the mine. The American Tunnel bulkhead is approximately 7950 feet from the portal at an elevation of 10660 feet. The depth of the American Tunnel bulkhead is approximately 2130 feet below the overlying ground surface. The Lake Emma outflow, 1550 feet above the bulkhead, is designed to be the outflow path for any groundwater entering the Sunnyside Mine between the F-Level bulkheads, elevation approximately 11570 feet, and the American Tunnel bulkhead.

The Terry Tunnel bulkhead on F-Level is approximately 650 feet below the Lake Emma outflow and approximately 1160 feet below the overlying ground surface. The Terry Tunnel bulkhead is located over 3800 feet from the Terry Tunnel portal. The Terry Tunnel bulkhead is designed to eliminate discharge of mine water from the Terry Tunnel portal. The Brenneman-Sunnyside F-Level bulkhead is 630 feet below the Lake Emma outflow and approximately 1200 feet below the overlying ground surface. The Brenneman-Sunnyside F-Level bulkhead is designed to prevent impounded Sunnyside Mine water from flowing into the Brenneman-Mogul Mine and exiting to the surface through Brenneman-Mogul Mine workings. The F-Level Terry Tunnel and Brenneman-Sunnyside bulkheads are also designed to provide hydraulic back pressure to resist near-surface fracture groundwater from entering the Sunnyside Mine between the F-Level, elevation approximately 11570 feet, and the Brenneman-Sunnyside B-Level bulkhead, elevation approximately 12140 feet.

The Brenneman-Sunnyside B-Level bulkhead is approximately 70 feet below the Lake Emma outflow and approximately 500 feet below the overlying ground surface. The Brenneman-Sunnyside B-Level bulkhead should complete the isolation of the Sunnyside Mine from the Brenneman-Mogul Mine by forcing any groundwater that may enter the Sunnyside Mine to exit through the Lake Emma outflow. Metallic sulfide oxidation products will be primarily, if not solely, from mine workings above the Lake Emma outflow elevation.

Impounding water in the Sunnyside Mine has the additional advantage of significantly reducing the availability of oxygen to metallic sulfide minerals. The Sunnyside Mine stopes below the Lake Emma outflow are presently open to air and percolating groundwater. Oxidation of metallic sulfides exposed in mine workings requires only oxygen, water and time to produce metallic and sulfate ions. The reduced oxygen availability when the stopes are flooded will significantly reduce the oxidation rate for exposed metallic sulfides. The restricted flow paths for water impounded in the mine will resist the replenishment of oxygen necessary for the oxidation process. The thermal gradient within the mine is the only energy source available to drive the convection process necessary to replenish oxygen depleted water within the Sunnyside Mine. This low strength energy source should be relatively ineffective in replenishing the oxygen content of the impounded water because of the flow restrictions presented by the mine workings.

The timbered shafts in the Sunnyside Mine represent the only reasonable convection path for movement of impounded water. The shafts in the Sunnyside Mine were deliberately placed outside the high-sulfide orebodies to protect them from mining operations. As such, shafts represent a minor potential contributor to metallic sulfide oxidation product production.

Abandoned stopes probably represent the major potential source for metal and sulfate ions. Draw chutes below stopes were, doubtless, timbered over when the stopes were abandoned. Any rock falling from the hanging wall of the abandoned stopes and now sitting on the timbered draw chutes will further resist convective movement of impounded water.

Water flow up or down ore passes in the Sunnyside Mine will be restricted because of the draw chutes at their bases. Rock which will also have raveled from the walls of the ore passes and which is currently lying on top of the draw chutes will further restrict water flow up or down the ore passes.

The design locations of the four bulkheads will restrict the potential for chemical attack on the concrete because of the difficulty in replenishing the sulfate ion concentration at bulkhead locations. The thermal gradient differential over the height of a tunnel is so small that it is doubtful that it would be sufficient to circulate water from the roof to the floor, let alone hundreds to thousands of feet along a tunnel to a water filled shaft. The American Tunnel bulkhead is 2486 feet from the nearest

shaft station. The Terry Tunnel bulkhead is 600 feet from a right angle turn and then several hundred more feet from the Terry Shaft. The Terry Tunnel bulkhead is an additional 1400 feet and around another corner from the Washington Shaft. The F-Level Brenneman-Sunnyside bulkhead is approximately 600 feet from the Washington Shaft and around several corners. The B-Level Brenneman-Sunnyside bulkhead is approximately 800 feet from the Washington Shaft and, again, around several corners.

The chemical attack on the bulkhead concrete by the initial sulfate ion concentration of the impounded mine water in contact with the bulkhead will be resisted by using Type V, sulfate resistant cement, as required by the ACI (ACI 318-89, Section 4.2) for exposure of concrete to "Moderate" sulfate concentrations from 500 ppm to 1500 ppm. The current "Moderate" sulfate ion concentration in the mine water is approximately 1040 ppm (Simon Hydro-Search, 1992, Appendix D). In addition, the sulfate resistance of the bulkhead concrete will be in accordance with the ACI code requirements for concrete in contact with "Very Severe", greater than 10000 ppm, sulfate ion concentrations. Concrete exposed to water with "Very Severe" sulfate ion conditions is required to use a water-cement ratio of 0.45 by weight and fly ash pozzolan. Fly ash, pozzolan, will be added to the design concrete mix in the amount of 16 percent of the cement by weight as recommended by ACI (ACI 318-89, Table 4.2.1) and Troxell et al (1968, p 104).

The bulkheads are designed to prevent leakage along the concrete/rock contact. The bulkhead designs include low-pressure grouting of the contact surface. The minimum grout pressure specified at the contact surface is 100 psi. Grouting is particularly important at the roof and the upper walls, where gravity will be least effective in filling cavities in or near the roof. As indicated by Einarson and Abel (1990), low-pressure grouting increases the resistance to leakage along the contact between the concrete and tunnel rock from 5 psi/foot to 41 psi/foot, with a factor of safety of four. The bulkhead lengths necessary to meet the 41 psi low-pressure design hydraulic pressure gradient along the bulkheads are presented in Table 2.

The mean concrete strength, f'_{CR}, used in determining the proportions of aggregate, cement and water is 4990 psi (ACI 318-89, Section 5.3.2.2 and Merritt, 1983, p 5-5). This, f'_{CR}, should conservatively yield a concrete strength of 3000 psi, or higher, under the most adverse working conditions. This high mean strength is necessary in the absence of compression test cylinder data for the specified mix. It may be possible to adjust the mix proportions when compression test data becomes available during bulkhead construction. Irregardless, compression test cylinders of the concrete placed in the bulkheads must be prepared to verify the strength of the concrete. The ACI specifies a minimum of 30 tests be performed to make a statistically significant evaluation of a concrete mix (ACI 318-89, Section 5.3.1.1 and ACI 214-77, Section 4.1). With only 231 total yards of bulkhead concrete, two 6-inch

Table 2. Sunnyside Mine concrete strength controlled bulkhead design lengths

INPUT: Assumptions: low pressure grouted, 41 psi hydraulic pressure gradient, 3000 psi concrete, concrete/rock contact shear strength (based on lower 110 psi concrete shear strength and ACI 318-89, Sec 11.8.6), 329 psi maximum concrete deep-beam shear stress at critical section (ACI 318-89, Sec 11.8.7), 164 psi plain concrete tensile strength (ACI 318-89, Sec 18.4.1)

Bulkhead Tunnel Ident.	Tunnel Design Height Width feet	Design Head feet (psi)	Pressure Gradient Length feet	Concrete Shear Strength Length feet	Plain Concrete Bending Length feet	Length Reco-mmend-ed feet
American Tunnel	13	1550 (670)	16.3	19.9	33.4	25
F-Level Terry Tunnel	11	650 (280)	6.9	7.1	18.3	8
F-Level Brenneman/ Sunnyside Connection	10	630 (270)	6.7	6.2	16.4	8
B-Level Brenneman/ Sunnyside Connection	9	70 (30)	0.7	0.6	4.9	3

diameter by 12-inch long test cylinders will have to be prepared for every five yards of concrete placed. One of the test cylinders can be used for a seven-day strength test, but one must be tested to measure the 28-day strength. The test cylinders should be taken randomly and not at the start or at the completion of pour. Adjustment of the concrete mix proportions during bulkhead construction would necessitate more frequent collection of test specimens.

The design concrete mix is 1 sack of Type V cement (94 lbs), to 235 lbs of fine aggregate, sand, to 330 lbs of well graded coarse aggregate and 15 lbs of fly ash, pozzolan. The mix proportions are 1:2.5:3.5 (cement, sand, gravel). One yard of concrete would contain 5.7 bags of cement (536 lbs), 1340 lbs of sand, 1881 lbs of well graded 3/4-inch maximum coarse aggregate and 86 lbs of fly ash, pozzolan. One yard of the specified concrete would have a dry weight of 3843 lbs/yard and a mixed weight of 4085 lbs/yard when the required 29 gallons of water is added. The approximate in place density of the concrete will be 151 lb/cu ft.

The specified mix would normally be considered an "oversanded" mix. However, the higher than normal sand content is designed to increase pumpability, i.e. slump, at the low water cement ratio of 0.45 required to resist the "Very Severe" design sulfate ion concentration in the mine water. High slump is necessary to facilitate the complete filling of the bulkhead forms. It will not be possible to vibrate the low water-cement ratio mix. Therefore, the concrete mix must flow easily under gravity to completely fill the space between the rebar and the face of the forms.

The Standard Handbook for Civil Engineers (Merritt, 1983, Table 8-4) indicates that a well-graded aggregate with a maximum size of 2 inches can be used with the mix proportions specified. However, it is recommended that 3/4-inch maximum aggregate size be used, again to enhance pumpability and minimize voids, segregation and "honey combing", particularly between the rebar mat and the face of the bulkhead forms. The fly ash is sufficiently fine grained that it does not occupy space in the mix, but fills voids that would otherwise be present in the concrete. Fly ash also decreases the permeability of the cast in place concrete.

Reinforced concrete is not necessary for water impoundment bulkhead construction. Plain, or mass, concrete has been successfully used on many occasions. The required length of a plain concrete bulkhead to resist deep-beam bending stresses for each of the four locations in the Sunnyside Mine is shown on Table 2. The dead or fluid load (D or F) acting on the bulkhead was multiplied by 1.4 (ACI 318-89, Section 9.2.1) and the plain concrete bending strength reduction factor of 0.65 was used. The bending strength reduction factor for plain concrete is from the 1971 ACI code, Section 9.3.2 and the 1977 ACI code, Section 9.2.1.5. The 1989 ACI code does not present a plain concrete bending strength reduction factor. The actual safety factor would appear to be 2.15. This higher than typical reduction factor for the bending strength of concrete may be the result of the high

variability of concrete tensile strength. Reinforcing bars, with the higher, more consistent and dependable tensile strength of steel, permit the installation of a shorter bulkhead. A reinforced concrete bulkhead relies on the rebar to carry the flexural tensile stresses at the air-side of the deep-beam designed bulkhead.

The reinforced concrete bulkheads were designed to support the factored dead and fluid loads (D and F) of the hydraulic pressure acting against the bulkheads. The ACI code requires that the dead and fluid loads be multiplied by 1.4 (ACI 318-89, Sections 9.2.1 and 9.2.5). In addition, the design flexure strength of the reinforced concrete deep-beam structure was multiplied by a strength reduction factor of 0.90 (ACI 318-89, Section 9.3.2.1). The shear strength of the reinforced concrete deep-beam structure was multiplied by a strength reduction factor of 0.85 (ACI 318-89, Section 9.3.2.3). These factors represent actual factors of safety for design of 1.56 for flexure and 1.65 for shear. Flexural loading of the bulkheads proved to be the critical criteria. This probably results from the design assumption that bulkhead loads are transferred to the tunnel walls solely in the horizontal direction. This in effect assumes that the roof and floor are not load carrying contacts. This is a conservative assumption, and the reinforcement bars are to be placed as a two-way mat, vertical as well as horizontal. A two-way path for load transfer will be provided but not included in the deep-beam strength calculations.

Two shear analyses were performed for each of the bulkheads. The shear strength (V_c) of the nominal 3000 psi design concrete mix (f'_c) is presented in ACI 318-89, Section 11.3.1.1 as twice the square root of the design strength, 110 psi for 3000 psi concrete. One shear analysis was performed for the bulkhead completely within concrete and just inside the rock/concrete contact. The concrete strength controls because of the higher strength of the wall rock at all of the bulkhead locations, as presented in Appendix B. The strength of the weakest of eleven bulkhead wall rock samples tested was nearly 3-1/2 times stronger than the 3000 psi design concrete strength, whereas the strongest was almost 11-1/2 times stronger. The other shear analysis was performed for the deep-beam critical section within the bulkhead (ACI 318-89, Section 11.8). The critical section for shear is 0.15 times the bulkhead span (ACI 318-89, Section 11.8.5), 1.95 feet in from the wall of the 13-foot wide American Tunnel, 1.65 feet for the 11-foot wide F-Level Terry Tunnel, 1.50 feet for the 10-foot wide F-Level Brenneman/Sunnyside Connection and 1.35 feet for the 9-foot wide B-Level bulkhead between the Brenneman Mine and the Sunnyside Mine. The calculation procedure for the critical section shear strength is described in the 1989 ACI reinforced concrete code, Section 11.8.7.

Hitching, or notching, of the bulkheads into the tunnel walls has not been included in the plans and specifications. Notching was not included because the concrete strength is lower than the rock strength. Failure of a concrete filled notch in the walls would occur through the weaker concrete. Over-excavating within the bulkhead locations would necessitate installation of rebar shear reinforcing to replace the strength of the stronger rock

removed. Notching has been effectively employed in situations where the rock is weaker than the concrete, which is not the case at the Sunnyside Mine. If additional shear reinforcement is considered necessary, which is not, it should be accomplished by installing rebar into specially drilled holes in the bulkhead location ribsides.

Leakage along the contact between the bulkhead concrete and the adjacent rock will be severely restricted, if not completely eliminated, by low pressure grouting of the interface. In addition, the specifications require that the roof and walls of the tunnel bulkhead locations be scaled to remove loose rock and washed to remove clay and oxidation products that are present to some extent at all bulkhead locations. The fresh rock exposed by cleaning of the roof and walls at the bulkhead locations will enhance bond strength between the concrete and the adjacent rock. Concrete-rock bond strengths typically range from 70 to 200 psi (Merritt, 1983, p 7-62). The concrete-rock bond strength was conservatively ignored in bulkhead design.

Western Colorado and the Sunnyside Mine lies in seismic risk Zone 1 with a maximum Mercalli magnitude intensity of VI and maximum peak ground acceleration between 0.08 g to 0.15 g (Lindeburg, 1990, p 13, 17, 18). Design for potential earthquake loading of the four bulkheads was performed using a "maximum credible earthquake" of magnitude 6.5 assigned to the Western Mountain Seismotectonic Province by Kirkham and Rogers (1981). The controlling earthquake for the Sunnyside Mine area would be centered along the Ridgeway fault 25 miles to the north (Sullivan et al, 1980; Weisser, 1982). Algermissen et al (1982) presented a method of assigning a 90 percent probability to the "maximum credible earthquake" not being exceeded in 250 years. This method predicts the peak acceleration from the "maximum credible earthquake" of 0.12 g at the Sunnyside Mine, with a horizontal component of 0.087 g (Knight Piesold & Co., 1988, p 65). The horizontal tunnel axes of the bulkheads means that the potentially damaging earthquake acceleration will be in the horizontal direction. The Terry Tunnel bulkhead is the only bulkhead with its horizontal axis adversely aligned toward the Ridgeway fault. However, all the bulkheads were conservatively treated as though their axes were adversely aligned directly toward the Ridgeway fault.

The design mass accelerated by the 0.087 g maximum credible horizontal earthquake component (90 percent probability "maximum credible earthquake" not exceeding of 6.5 magnitude along the Ridgeway fault within a 250 year period) that must be resisted by the bulkhead is the mass of water that has a line of sight path to the bulkhead plus the mass of the bulkhead. The earthquake acceleration force of impounded water that does not directly face the bulkhead will be borne by the rock walls the accelerated water does face. The ACI earthquake design procedure (ACI 318-89, Section 9.2.3) for reinforced concrete structures requires a load factor of 1.4 times the calculated earthquake force (E). The earthquake load (E) is added to a factored fluid load (F).

However, under earthquake loading the factor for the dead and fluid load force (D and F) acting on the bulkhead is reduced to 1.05 from the 1.4 factor for long term sustained fluid load design. Apparently the dynamic nature of the earthquake load (E) has been found in practice not to be as hazardous to reinforced concrete structures as the long term dead and fluid loads (D and F). Reinforced concrete structures are subject to long term creep when subject to near failure dead and fluid load compressive stresses (Troxell, et al, 1968, p 313).

BULKHEAD DESIGNS

Certain features of the design of all four bulkheads are common. All bulkheads will utilize the same concrete mix to achieve the same 3000 psi concrete strength. The 1:2.5:3.5 cement, sand, gravel (Type V cement, fine aggregate, well-graded coarse aggregate with a 3/4-inch maximum) mix with the addition of fly ash, pozzolan, in the amount of 16 percent of the cement weight was described earlier. A 0.45 water/cement ratio, by weight, will be utilized for construction of all bulkheads. All bulkheads will utilize two-way tensile reinforcement rebar, a minimum of 3-1/2 inches from the air-side form. All bulkheads will have the same shrinkage and temperature rebar cage a minimum of 3 inches from the water-side face. All the shrinkage and temperature rebar is to be #6 bars two-ways on 12-inch centers. The specified length of the rebar for each bulkhead is the maximum width or height dimension for the particular bulkhead location. The irregular shape of the tunnel cross sections will probably require cutting most the rebar at the bulkhead sites. The individual pieces of rebar can be in direct contact with the wall rock, may be socketed in mortar in 1-foot or shorter specially drilled holes but must not be more than 6 inches from the tunnel wall, roof or floor at either end of the bar. Bars can be spliced provided the code required overlap distances, development lengths, are provided, 82 inches for the #10 bars and 48 inches for the #6 bars.

The design requirements versus design specifications together with the grouting specifications for the individual bulkheads are presented in Table 3. The factors of safety, presented for the concrete and steel rebar reinforced bulkheads, are in excess of the code required factors of 1.4 for the dead, or fluid, load, 0.90 for tensile strength and 0.85 for shear strength.

Low-pressure grouting of the bulkheads should not be attempted until at least 7 days after completely filling the bulkhead form. A 28 day delay between concrete pouring and grouting is recommended, if possible. Minimum and maximum grout pressures are specified for the contact between the concrete and the rock roof and walls. The optimum position for the grouting points at the grout ring locations are high points in the roof and wide locations on the ribs. The filling of these potential voids with the neat

Table 3. Sunnyside Mine design requirements vs design specifications and recommended minimum and maximum grouting pressures for low-pressure grouting of bulkheads

INPUT: Assumptions: low-pressure grouted, 41 psi hydraulic pressure gradient, 3000 psi concrete, 110 psi ACI allowable concrete/rock contact shear strength (based on lower strength of concrete and ACI 318-89, Sec 11.8.6), deep-beam shear strength at critical sections calculated for individual bulkheads using ACI 318-89, Sec 11.8.7, rebar 3.5-in. from downstream (air-side) face, factors of safety in brackets calculated table values, shear stresses include the 1.4 fluid load factor (ACI 318-89, Sec 9.3.1) and 0.85 shear strength reduction factor (ACI 318-89, Sec 9.3.2.3)

Bulkhead Tunnel Ident.	Length Reco-mmended (ft)	Design Hydraulic Gradient (psi/ft)	Perimeter Concrete Shear Stress (psi)	Critical Section Shear Stress (psi)	Recommended Grout Pressure from - to (psi)	
American Tunnel	25	27 (1.53)	87 (1.26)	204 (1.48)	100	500
F-Level Terry Tunnel	8	35 (1.14)	97 (1.10)	232 (1.35)	100	200
F-Level Brenneman/ Sunnyside Connection	8	34 (1.20)	85 (1.28)	203 (1.49)	100	200
B-Level Brenneman/ Sunnyside Connection	3	10 (4.05)	23 (4.82)	58 (4.01)	100	200

cement grout is more important than maintaining an exact positioning of the grout points or location of the rings. Grouting is to continue until refusal at the selected grouting pressure, but not less than the minimum specified 100 psi. In most cases when low pressure grouting, and when the concrete pour has been carefully done, grout refusal is almost immediate. Grout take occurs when the grout location along the contact intersects a void. If, after the injection of two bags of grout, grout take continues without reaching the selected, or minimum, grout pressure, grouting is to be temporarily stopped in that hole, a new grout hole occupied and grouted. Any grouting point in a bulkhead that was unsatisfactory is to be redrilled and grouted after waiting a minimum of one day. This process of cycling through the holes on that bulkhead is to continue until grout pressure either builds up to the minimum pressure or the grout exits around the available face of the bulkhead. Grout exiting around the bulkhead rock contact indicates complete filling of near surface void(s). In the later case, a great deal of judgment will be required to determine when to stop grouting because the opposite side of the American Tunnel, F-Level Brenneman/Sunnyside and B-Level Brenneman/Sunnyside connection bulkheads will not available for inspection. In the case of the three shorter bulkheads, if grouting is unsatisfactory it may be possible to build a concrete extension on the water-side of the bulkhead and repeat the very time consuming and expensive grouting process.

The grouting points for the three shorter bulkheads are to be on 5-foot centers, approximately, along the roof and walls. This will amount to one ring of grout holes centered along the length of the bulkhead. It may be advantageous to install short plastic pipes in the forms on the grouting side of the three shorter bulkheads to guide the drill through the shrinkage and temperature rebar cage. It will be difficult to accurately control the drill to maintain positioning of the grouting points. Close, plus or minus two feet, is acceptable, provided the grouting point is at the contact between concrete and rock. The driller will have to be relied upon to detect the difference between the over 10000 psi rock and the 3000 to 5000 psi concrete. Intersection of a void will not be sufficient to stop drilling the hole. Positive verification of rock is required. A grout hole that does not cut the contact is basically useless. The grout holes are to be grouted full after successfully grouting a grout point.

The longer American Tunnel bulkhead should have three grouting rings, one ring of grout holes approximately 6 feet from the water-side of the bulkhead, one approximately 6 feet from the air-side of the bulkhead and one approximately in the center of the bulkhead length. Three back and two rib holes on each wall are recommended for each ring. The same rough 5-foot spacing between grouting points is recommended. It will probably be necessary to install short plastic pipes in the face of the form on the air-side of the American Tunnel bulkhead to prevent drilling into the #10 bars on 7-inch centers of the rebar cage. Grouting of an individual grout point is more likely to meet the refusal

specification on the first trial in the American Tunnel case because of the length of the bulkhead. However, the possibility of more grout take should also be anticipated, three bags instead of two maximum, per hole.

Bending stress developed in the one-way deep-beam designed bulkhead controlled the design of all the bulkheads. This was discussed previously, indicating the potential doubling of the safety factor by the actual two-way rebar specification. Table 4 presents the tensile reinforcement rebar area required to support the design fluid load and the rebar specifications for the four bulkheads. The actual rebar area provided is presented. The design fluid load is 1.4 times the maximum possible load as required by ACI 318-89, Section 9.2.1. The design tensile reinforcement is factored by 0.90 as required by ACI 318-89, Section 9.3.2.1. Table 5 indicates the supportable design load for each bulkhead reinforcement design. The factors of safety listed in Table 5 are in excess of the load increase and strength decrease factors required by the ACI code.

AMERICAN TUNNEL BULKHEAD

The design of the American Tunnel bulkhead differs from the other three bulkheads because of its length and because it will be necessary to provide for the flow of water through the bulkhead location both during construction and after construction for the 28 day curing period. The pipe will have to be long enough to bypass the water in the tunnel from the upstream coffer dam to sufficiently far below the bulkhead site to provide relatively dry working conditions. The design flow for the water bypass pipe is 2500 gpm (5.6 cfs) under five feet of head. A single 11-inch inside diameter pipe is required for the design flow under the head specified. Any nominal 12-inch diameter flanged steel pipe will provide the design flow capacity. The 5-foot head will be provided by the coffer dam to be erected upstream of the bulkhead location. The coffer dam can be constructed from the ballast and broken rock dug from the bulkhead location, provided it is sufficiently impermeable to prevent excessive leakage during bulkhead construction. Bulkhead construction can probably be facilitated by constructing a more impermeable concrete coffer dam on the excavated rock floor of the tunnel. A concrete coffer dam should positively prevent water from entering the bulkhead construction area.

The inlet water bypass pipe is to be through a flat surface, square edge, inlet. The flat surface, square edge, inlet is designed to reduce inlet turbulence and inlet flow restriction which would reduce the flow rate. The required flat surface can be the field fabricated from sheet metal or plywood backed by the coffer dam material. Of course, the upstream face of a concrete coffer dam provides its own flat surface, square edge, pipe entrance.

Table 4. Sunnyside Mine rebar specifications for bending stress design bulkhead

INPUT: Assumptions: rebar 3.5-in. from downstream (air-side) face, shear stresses include the 1.4 fluid load factor (ACI 318-89, Sec 9.3.1), 0.90 tensile strength reduction factor (ACI 318-89, Sec 9.3.2.1) and 0.85 shear strength reduction factor (ACI 318-89, Sec 9.3.2.3), 60,000 psi rebar yield strength (f_y)

Bulkhead Tunnel Ident.	Tunnel Design Height Width (ft)	Length Reco-mmend-ed (ft)	Steel Area Required ($in.^2/ft$)	Rebar Size	Recommended Spacing (in.)	Steel Area Provided ($in.^2/ft$)
American Tunnel	13	25	2.159	#10	7	2.177
F-Level Terry Tunnel	11	8	2.111	#10	7	2.177
F-Level Brenneman/ Sunnyside Connection	10	8	1.683	#10	9	1.693
B-Level Brenneman/ Sunnyside Connection	9	3	0.429	# 6	12	0.440

NOTE: Rebar 3.5-in. from air-side face

Table 5. Supportable design hydraulic loads at allowable bending stresses for tunnel bulkheads

INPUT: Low-pressure grouted, 41 psi hydraulic pressure gradient, 3000 psi concrete, 110 psi allowable concrete shear strength (based on lower strength of concrete and ACI 318-89, Sec 11.8.6), deep-beam shear strength at critical sections calculated for individual bulkheads using ACI 318-89, Sec 11.8.7 and rebar specified in Table 2, factors of safety in brackets calculated table values, shear stresses include the 1.4 fluid load factor (ACI 318-89, Sec 9.3.1), 0.90 tensile strength reduction factor (ACI 318-89, Sec 9.3.2.1) and 0.85 shear strength reduction factor (ACI 318-89, Sec 9.3.2.3)

Bulkhead Tunnel Ident.	Length Reco-mmended (ft)	Rebar Spacing (in.)	Potential Head - ft (psi)	Supportable Head - ft (psi)	Factor of Safety
American Tunnel	25	7	1550 (670)	1570 (680)	1.01
F-Level Terry Tunnel	8	7	650 (280)	670 (290)	1.03
F-Level Brenneman/ Sunnyside Connection	8	9	630 (270)	634 (275)	1.01
B-Level Brenneman/ Sunnyside Connection	3	12	70 (30)	80 (35)	1.14

A 12-inch "standard weight, schedule 40", flanged steel pipe is satisfactory for the water bypass application. Twelve-inch "standard weight" pipe is 12.750 inches O.D. and 12.000 inches I.D., has a wall thickness of 0.375 inches, weighs 49.56 lbs/foot and has a burst pressure in excess of 3000 psi. This is a factor of safety of more than 4.5 in relation to the maximum head of 670 psi.

The top to bottom bulkhead construction sequence will divert the more corrosive lower pH, 5.9 to 5.7, water presently exiting the Terry Tunnel to the present essentially neutral, 7.3 pH, water passing the American Tunnel bulkhead location (Stock & Walston, 1992, fig 11 & p 47). Larry Perino, Superintendent of Technical Services, reports pH levels in the range of 3.5 to 4.0 for the Terry Tunnel drainage during low-flow periods. The worst-case moderately corrosive mine water passing through the pipe does not necessitate a special corrosion resistant steel for the short construction and diversion period. Measures can be taken to extend pipe life and to prevent pipe corrosion. The use of "extra strong, schedule 80" flanged steel pipe will extend pipe life. "Extra strong" steel pipe is 12.750 inches O.D. and 11.750 inches I.D., has a wall thickness of 0.500 inches, weighs 65.42 lbs/foot and has a burst pressure of nearly 4000 psi. Lime or limestone dumped in the stilling pond upstream from the coffer dam in the American Tunnel will raise the pH of the mine drainage water and inhibit the corrosion potential of the mine drainage water during the diversion and construction period and for some time after bulkhead closure.

The water bypass pipe will require support every 5 feet through the bulkhead. Concrete block is recommended for support. Similar support will be required upstream of the bulkhead and for the temporary pipe extension downstream of the valve immediately below the bulkhead. Wire ties to rock anchors in short holes drilled in the adjacent wall and floor will be required within the bulkhead to prevent movement of the pipe during concrete placement.

An additional 1-inch diameter "standard weight, schedule 40" pipe is specified through the bulkhead. The purpose of this pipe is to measure hydraulic pressure behind the bulkhead and permit calculation of the level of impounded water after the bulkhead bypass pipe valve is closed. Standard threaded couplings will be satisfactory for this pipe. The pipe should be at a convenient level for reading and a minimum distance outside the air-side bulkhead form so as not to interfere with construction or be damaged. It may facilitate work within the bulkhead to place this pipe near, about one foot, the far rib from the water bypass pipe. The 25-foot length of this pipe will necessitate hanging of this pipe from wire ties from short rock anchor supports at a minimum of three locations within the bulkhead to maintain its position during placement of the concrete.

The pressure measuring pipe is to be fitted with a ball valve on the air-side of the bulkhead with a pressure gage and cap outside, downstream from, the valve. The nominal 1-inch diameter

"standard weight, schedule 40", 1.315-inch O.D. and 1.049-inch I.D., pipe will be subjected to a maximum design thrust of 580 lbs. Without couplings the thrust stress thru the bulkhead will be less than 0.5 psi in shear. The bond shear strength for rebar is 100 to 300 psi at the loaded end when slip starts and 300 to 800 psi when the bar pulls from the concrete (Troxell, et al, 1968, p 236). The ACI specifies the development length for smooth wire of the diameter of nominal 1-inch pipe to be determined the same way as deformed wire (ACI 318-89, Section 12.2.2 and 12.7.3). This design specifies 60 inches to develop the full strength of a 1.315-inch diameter steel bar, i.e. the bar would pull in two rather than pull out of the concrete. The couplings along the pipe provide additional shear resistance. A threaded foot plate can be installed at the upstream end of the pipe to provide positive resistance to shear displacement.

Figure 1 presents a schematic of the air-side rebar curtain for the American Tunnel bulkhead. The location for the water bypass pipe penetration through the rebar curtain is not critical, except it cannot be so close to the floor or wall to impede the gravity placement of the concrete. Figure 2 is a detail of the pipe penetration through the air-side rebar curtain. The purpose of the four 5-foot long #6 bars is to reinforce the concrete corners of the rebar cage penetration and prevent corner fractures from developing. The 1/2-inch diameter by 2-inch long headed rebar studs shown are to be welded to the pipe, two diametrically opposed studs every foot along the pipe within the bulkhead for a total of 46 studs. The stud orientation is to be rotated 90^0 every foot. The studs can be vertical and horizontal, or at 45^0 inclination, or a combination of both. Ease of welding should govern stud location on the pipe. Each properly welded stud has a design shear resistance of 5100 lbs (AISC, 1989, Table I4.1) when imbedded in 3000 psi concrete. These studs are designed to resist the 672 psi maximum head thrust on a 12-inch I.D. pipe of 76000 lbs that may develop after the valve is closed. Fifteen studs should be sufficient. The excess number of studs is specified because of the probable difficulty of obtaining a proper field weld.

The specification of shear studs conservatively eliminates any reliance on skin friction between the pipe and the concrete. Design bond shear strength between the pipe and the concrete is 6.3 psi, well below probable bond strength. The shear resistance of the pipe flanges was also conservatively ignored. This conservative approach was specified because of the critical nature of the bypass pipe and its flow potential in the case of failure.

The specified water bypass pipe gradient is 0.01, or 3 inches through the 25-foot long bulkhead. This gradient should be maintained to the inlet at the coffer dam and for the downstream extension below the valve. The gradient is necessary for the design flow rate of 2500 gpm. Figure 3 is a schematic of the pipe penetration through the water-side rebar curtain.

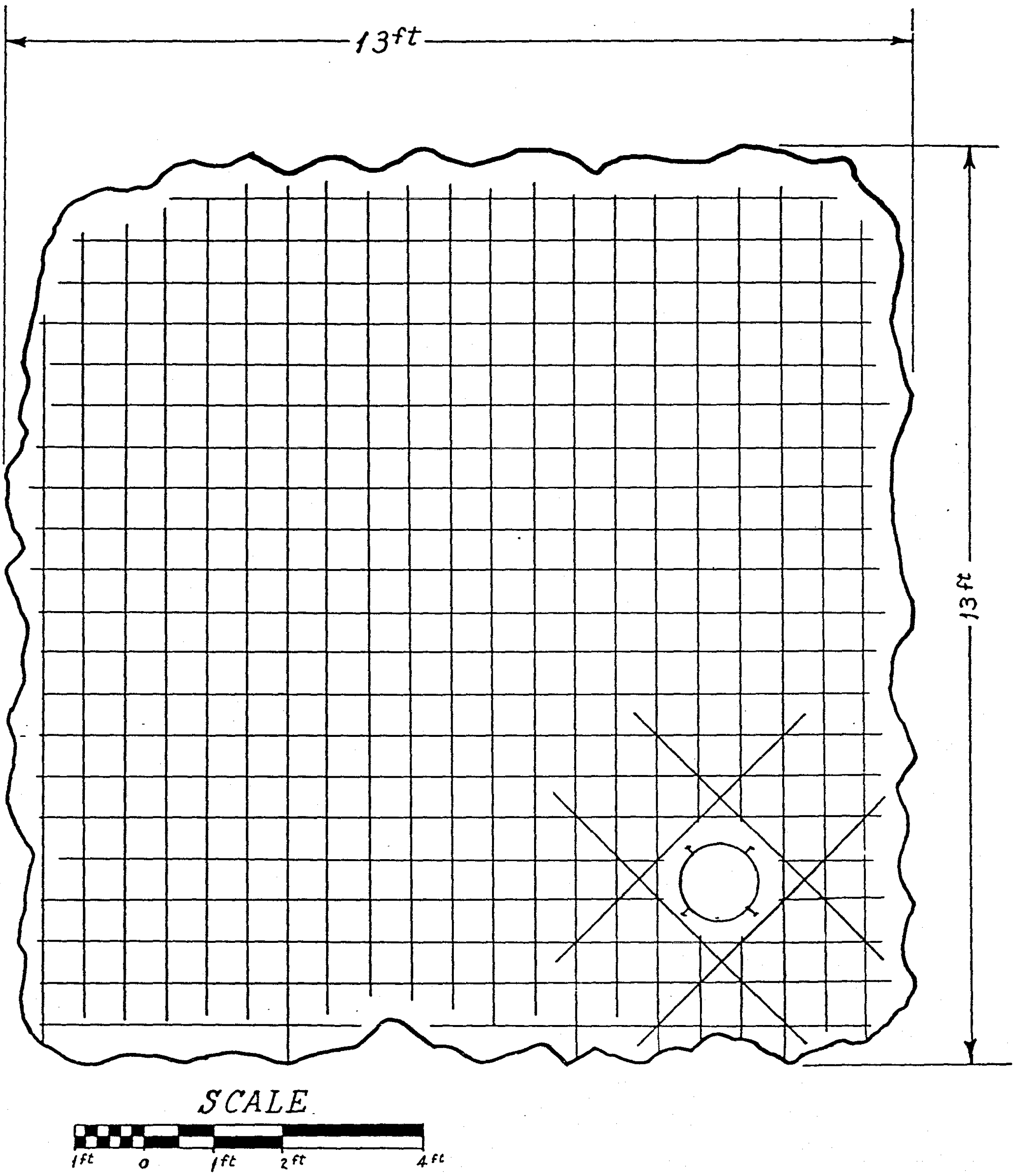

Figure 1. Air-side rebar cage (mat) for flexural reinforcement in the American Tunnel, #10 bars, 7-in. spacing, 3.5-in. minimum depth of cover.

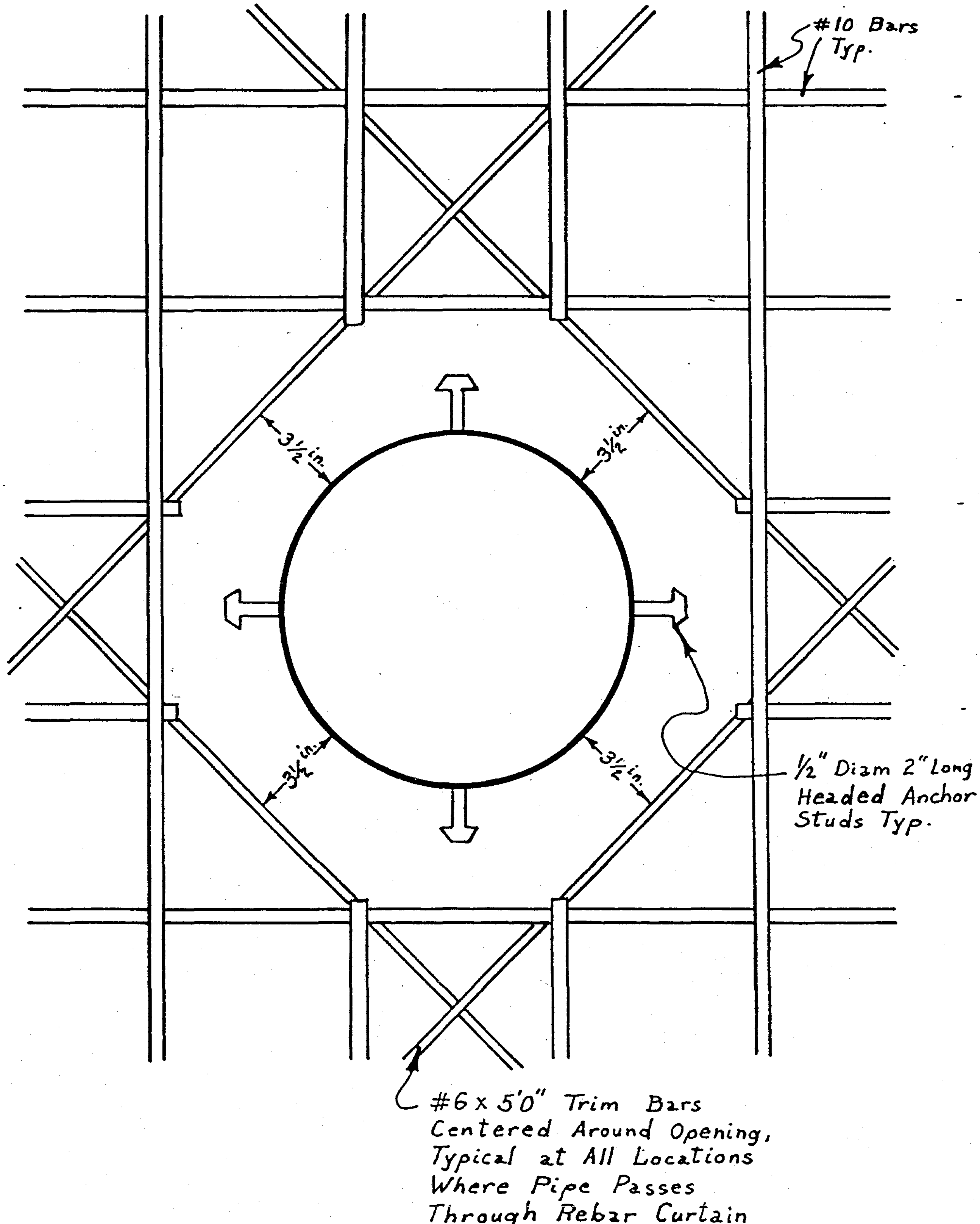

Figure 2. Details of air-side pipe and rebar cage location.

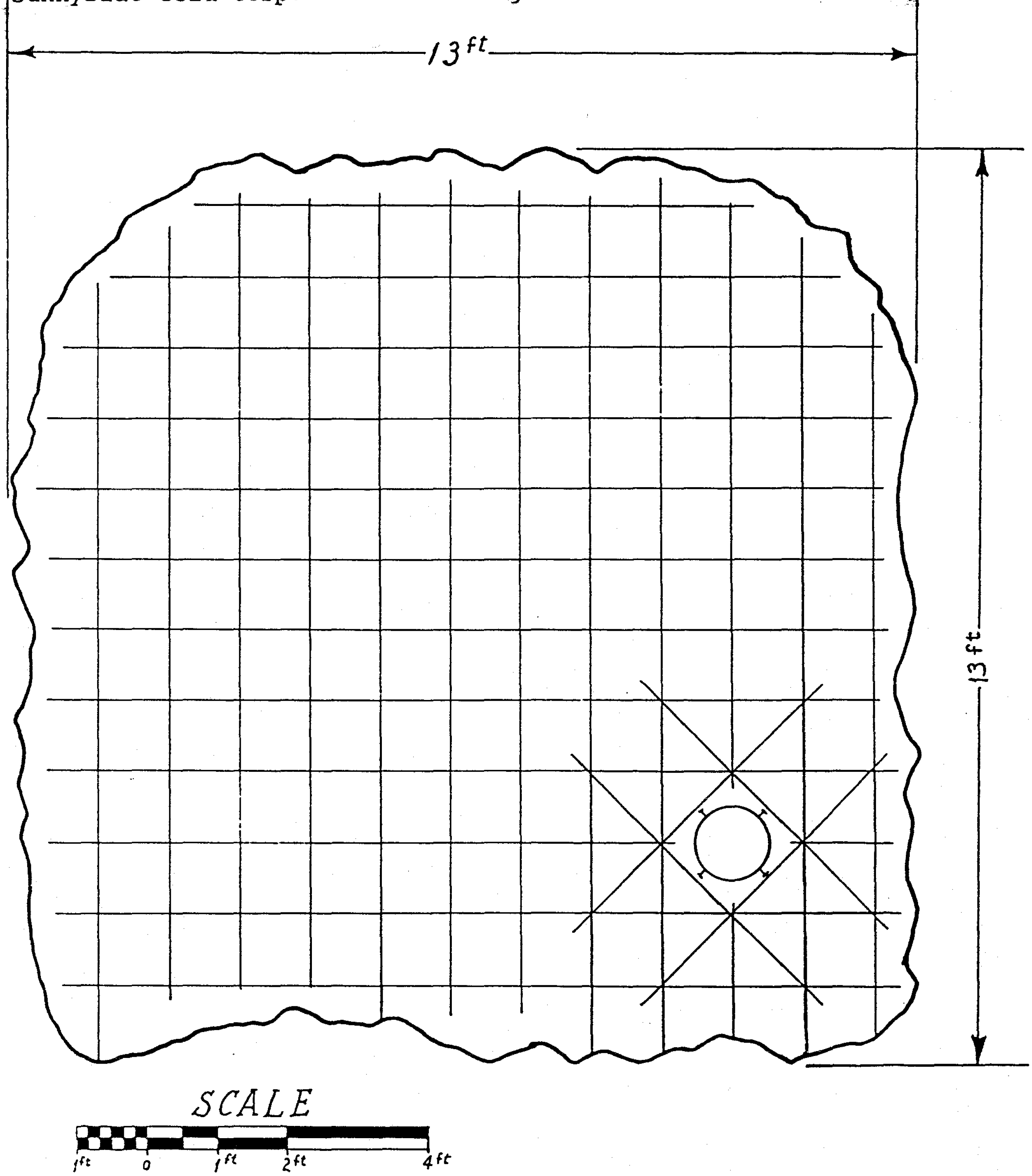

Figure 3. Water-side rebar cage (mat) for shrinkage and temperature control in the American Tunnel, #6 bars, 12-in. spacing, 3-in. minimum depth of cover.

Support of the upstream, water-side, bulkhead form can be accomplished by several means. An open braced 2 x 4-inch wood frame can be constructed, with plywood sheeting nailed to the 2 x 4-inch frame from the inside of the bulkhead. It is recommended that the form also be braced with rebar socketed in short, less than 12-inch long, mortar filled drill holes in the tunnel ribs. The form could be wedged against the upstream rebar. The form should not be connected by metal ties to the shrinkage and temperature rebar. Such metal ties could provide a long term corrosion path into the bulkhead. Similarly, the diversion and pressure sensing pipes should not be physically tied to the shrinkage and temperature rebar cage.

Erection of the rebar curtains can be facilitated by first socketing two horizontal rebar into short, 6-inch to 12-inch deep mortar filled drill holes in the tunnel ribsides. For the #6 shrinkage and temperature cage, Figure 3, this would position horizontal bars three or more inches from the face of the form with the vertical bars tied to the inside the horizontal bars. One horizontal positioning bar would be placed near the top of the tunnel and the other below the pipe penetration. These horizontal positioning rebar should provide a solid frame for the assembly and tying the rebar cages. The second step should probably be to stand and tie in the two vertical bars at the sides of the pipe penetrations. The only specified restriction for the length of the bars is that they not be more than 6 inches from either tunnel wall in the case of horizontal bars or the roof or floor in the case of vertical bars. It would seem reasonable to next place and tie in one or two vertical bars near the opposite tunnel wall. All horizontal bars would then be fitted into the space between the form and the rebar cage, positioned and tied. The final step would be to tie in all remaining vertical rebar.

The air-side cage of #10 bars, Figure 1, would be placed in exactly the same sequence except the horizontal bars would be toward the center of the bulkhead and weigh up to 56 lbs. The exact position of the form on the downstream face can be adjusted to provide the minimum cover of 3-1/2 inches. Having the form one or two inches out of the exact design location will not be critical to the functioning of the 25-foot long bulkhead.

Filling of the form will be difficult to control. As recommended by Troxell, et al (1968, p 189) the concrete discharged from the slickline should not impact the upstream water-side rebar cage or form. Permitting the concrete to strike against the form face and ricochet on the bars causes separation and "honey combing" at the base. The concrete should build up on the floor and flow around the bars to the form. Filling of the upper corners of the form will probably necessitate three flexible hose slicklines, one in the center of the tunnel and one at each upper corner of the tunnel. The 13-foot final depth of the pour eliminates hand distribution of concrete to the upper corners of the tunnel. It is

recommended that the slicklines be suspended from rings spaced at no more than 2-foot centers and wired to short anchor bolts in the roof. The slicklines are to be retracted when the concrete buildup toward the upstream end of the form prevents pumping or forces the flexible hose slickline backwards or sideways.

The majority of the concrete would be pumped through the central slickline, with only the finishing corner filling concrete pumped through the corner slicklines. The corner filling should follow by one to three hours, depending on tunnel temperature, and as many feet as possible behind the central slickline filling. Sand/cement grout can be employed to fill the upper corners of the form if the concrete from the upper corner slicklines is not completely filling the upper corners of the form. Sand/cement grout has successfully been used in bulkhead construction under hydraulic heads of over 4000 feet (World Mining, 1969, p 21-22).

The concrete pour into the bulkhead should be essentially continuous. As recommended by Troxell, et al (1968, p 174) the fresh concrete surface should not be allowed to set exposed more than 1-1/2 hours before being covered by the next layer of freshly mixed concrete if the concrete mixing temperature, i.e. the tunnel temperature, is 70^0F. This time delay period can be 3 hours if the concrete mixing and tunnel temperature is 50^0F. If the mixing and tunnel temperature is above 70^0F the delay time must be shortened. Mixing time effects 28-day concrete strength (Troxell, et al, 1968, p 171). A minimum mixing time of ten minutes is specified. The strength of concrete increases for mixing times from 5 to 10 minutes when using multiple cu yd machines. Mixing times in excess of 10 minutes provide no strength increase.

The anticipated critical path bulkhead construction sequence for the American Tunnel bulkhead is 1) combined removal of the rail within the length of the tunnel that will be affected by bulkhead and coffer dam construction and scaling and washing of the roof and walls of the bulkhead location, 2) the combined construction of the coffer dam, laying of the pipe, attachment of the valve and diversion of water through the pipe, 3) complete removal of tunnel ballast and loosened blast damaged rock on the floor of the tunnel down to solid rock through the bulkhead section, 4) construction of the water-side concrete form, 5) welding of the studs to the pipe, starting at the water-side end of the bulkhead accompanied by, as soon as space is available, erection of the water-side rebar cage, 6) combined installation of the 1-inch diameter pressure gage pipe and hanging of the retractable slicklines along the roof of the bulkhead section of the tunnel from rings supported by short anchor bolts in the roof, 7) erection of the air-side rebar cage with the short plastic guide pipes wired to the rebar cage, 8) construction of the lower approximately ten feet of the air-side form with the plastic drill guide pipes extending through the form, 9) continuous pumping of concrete to the far end of the bulkhead and filling of the form, 10) progressive withdrawal of the slickline as resistance to pumping is encountered, 11) closure of the top of the air-side form and 11) completion of filling of the form.

F-LEVEL TERRY TUNNEL BULKHEAD

The maximum 11-foot wide by 11-foot high Terry Tunnel bulkhead is unique in that access is possible to both sides during construction. It is assumed that air-side access will not be possible during the construction period because of snow conditions. The air-side bulkhead face will, however, be seasonally accessible after impoundment. Flow from the Terry Tunnel is reported by Stock and Walston (1992, p35) to vary "from 82 gpm in autumn to at least 1400 gpm during spring runoff." Terry Tunnel drainage will be intercepted and diverted to the American Tunnel before bulkhead construction. Therefore, the Terry Tunnel bulkhead will not include a water diversion pipe.

Table 4 presented the required bulkhead length, 8 feet, and deep-beam bending stress reinforcement, #10 bars on 7-inch centers, to support the maximum possible 650-foot head. Table 5 presented the actual supportable design head for the bulkhead, 670 feet. The design head includes the ACI required 1.4 factor for the actual maximum head and the 0.90 factor for the design tensile strength under one-way deep-beam bending. The mean actual factor of safety for the Terry Tunnel bulkhead is 1.60.

A 1-inch diameter "standard weight, schedule 40" pipe is specified through the bulkhead. The purpose of this pipe is to permit measurement of the hydraulic pressure behind the bulkhead and calculation of the elevation of impounded water after closure of the American Tunnel bulkhead bypass pipe valve. Standard threaded couplings will be satisfactory for this pipe. The pipe should be at a convenient height for reading. This pipe is to be fitted with a ball valve on the air-side of the bulkhead with a pressure gage and cap outside, air-side, the valve.

Figure 4 presents a schematic of the air-side rebar curtain for the Terry Tunnel bulkhead. Figure 5 presents the shrinkage and temperature rebar curtain.

Erection of the Terry Tunnel rebar curtains will be from inside the Sunnyside Mine, with the air-side bending stress reinforcement cage, Figure 4, first. Erection can be facilitated by first socketing two #10 horizontal positioning rebar into short, 6-inch to 12-inch deep mortar filled drill holes in the tunnel ribsides 3-1/2 inches from the face of the air-side form. One horizontal positioning bar would be placed near the top of the tunnel and the other near the floor. Two, near rib vertical rebar would then be tied to the horizontal positioning bars. The third step should probably be to fit and tie all the remaining horizontal rebar to the two vertical bars. The final step would be to tie in all the remaining vertical bars. The procedure would be repeated for the shrinkage and temperature rebar curtain, Figure 5, except the water-side form would be placed after building the rebar cage.

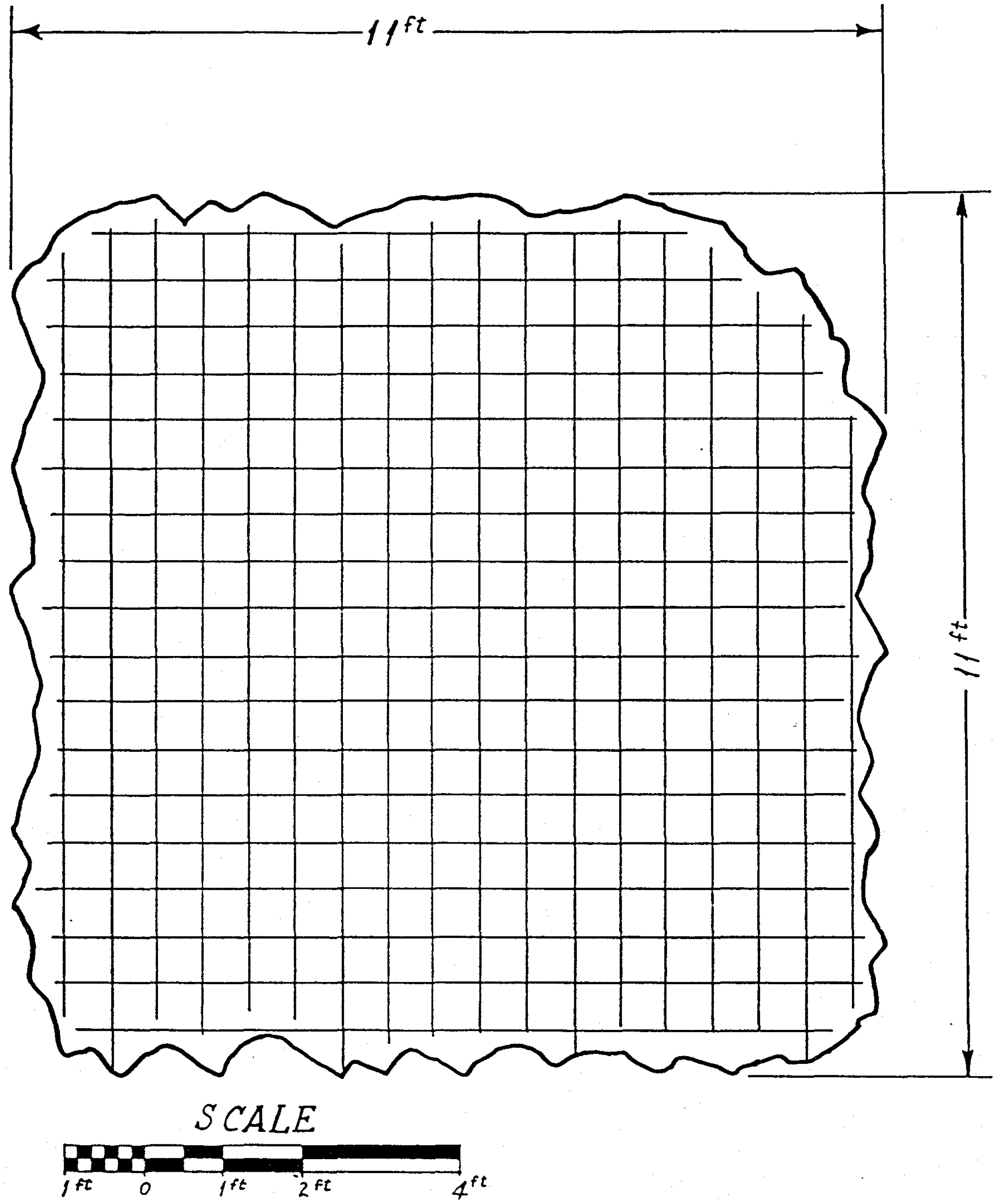

Figure 4. Air-side rebar cage (mat) for flexural reinforcement in the F-Level Terry Tunnel, #10 bars, 7-in. spacing, 3.5-in. minimum depth of cover.

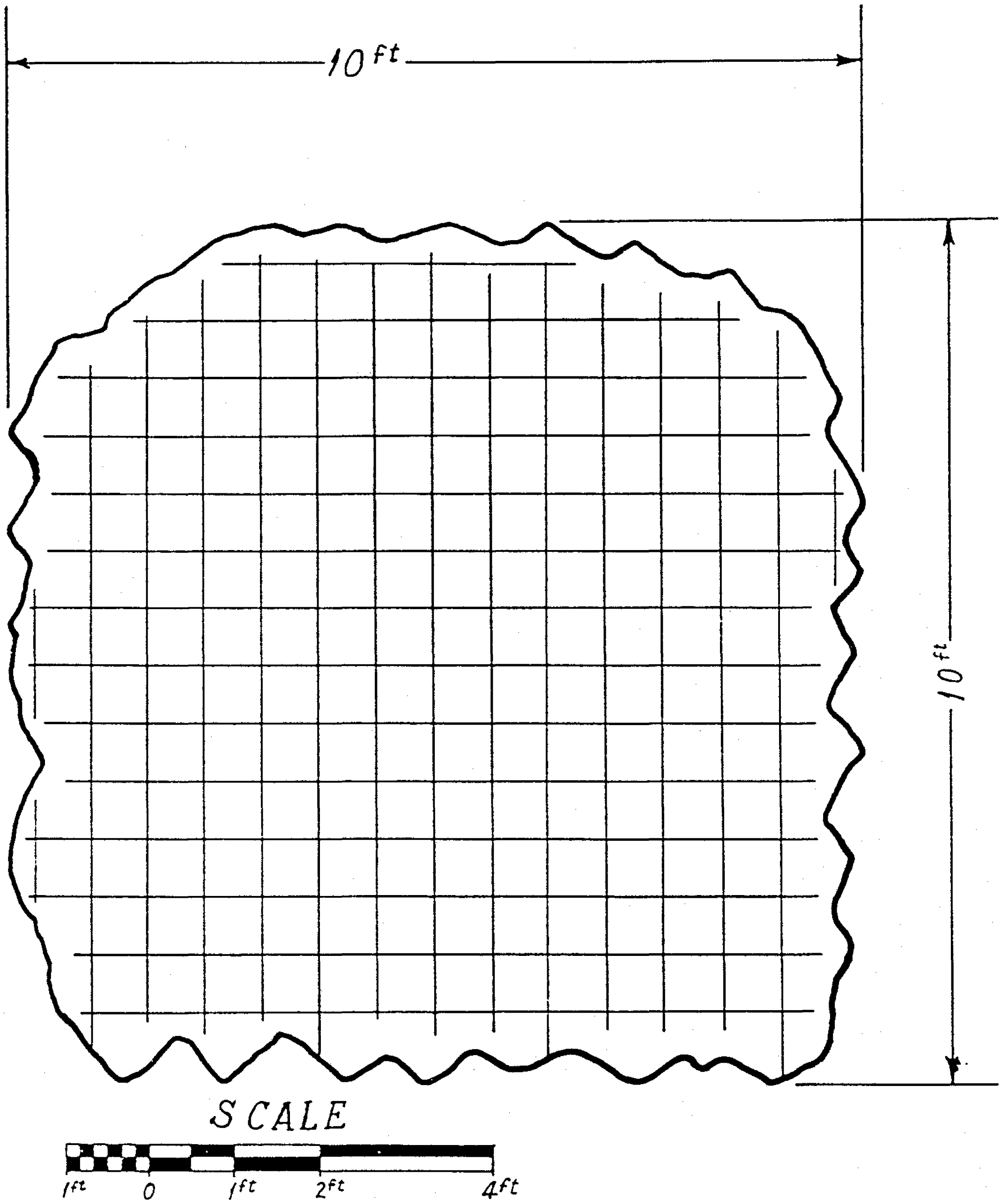

Figure 5. Water-side rebar cage (mat) for shrinkage and temperature shrinkage control in the F-Level Terry Tunnel, #6 bars, 12-in. spacing, 3-in. minimum depth of cover.

The upper two feet of the water-side form would be left open for filling the form. It should be possible to fill almost the entire 8-foot long Terry Tunnel form through the shrinkage and temperature rebar cage. The slickline will have to be repositioned for final filling of the roof and upper corners of the form as the water-side form is closed.

The concrete pour into the bulkhead should be essentially continuous. As recommended by Troxell, et al (1968, p 174) the fresh concrete surface should not be allowed to set exposed more than 1-1/2 hours before being covered by the next layer of freshly mixed concrete if the concrete mixing, and tunnel, temperature is 70^{0}F. This time delay period can be 3 hours if the concrete mixing and tunnel temperature is 50^{0}F. Larry Perino (1992) reports the Terry Tunnel temperature to be slightly lower than 50^{0}F. Mixing time effects the 28-day concrete strength (Troxell, et al, 1968, p 171). A minimum mixing time of ten minutes is specified. The strength of the concrete increases for mixing times from 5 to 10 minutes when using multiple cu yd machines. Mixing times in excess of 10 minutes provide no strength increase.

The anticipated critical path bulkhead construction sequence for the Terry Tunnel is 1) diversion of water draining from the Terry Tunnel, 2) complete removal of tunnel ballast and loosened blast damaged rock on the floor of the tunnel down to solid rock through the bulkhead section, 3) scaling and washing of the roof and walls in the bulkhead area, 4) construction of the air-side concrete form, 5) erection of the air-side bending stress rebar curtain, 6) installation of the 1-inch diameter pressure gage pipe, 7) erection of the water-side shrinkage and temperature rebar cage with the short plastic guide pipes wired to the rebar cage, 8) construction of the lower approximately 8 feet of the water-side form with the plastic drill guide pipes extending through the form, 9) continuous pumping of concrete through the water-side rebar cage and filling of the form, 10) progressive withdrawal of the slickline as resistance to pumping is encountered, 11) closure of the top of the water-side form and 12) completion of filling of the form.

F-LEVEL BRENNEMAN/SUNNYSIDE CONNECTION BULKHEAD

Access is not now available from what will be the air-side of the maximum 10-foot wide by 10-foot high F-Level bulkhead location in the tunnel connecting the Brenneman and Sunnyside Mines. Access is not anticipated in the future. Therefore, no water pressure measuring pipe is included in this bulkhead. Construction will be facilitated because there is no water flow along the tunnel connecting the Brenneman and the Sunnyside Mines. Therefore, no water diversion pipe will be necessary for the bulkhead isolating the Brenneman Mine from the Sunnyside Mine on the F-Level.

Table 4 presented the required bulkhead length, 8 feet, and deep-beam bending stress reinforcement, #10 bars on 9-inch centers,

to support the maximum possible 630-foot head. Table 5 presented the actual supportable design head for the bulkhead, 634 feet. The design head includes the ACI required 1.4 factor for the actual maximum head and the 0.90 factor for the design tensile strength under one-way deep-beam bending. The mean actual factor of safety for the F-Level Brenneman/Sunnyside Connection bulkhead is 1.57.

Figure 6 presents a schematic of the air-side rebar curtain for the F-Level Brenneman/Sunnyside Connection bulkhead. Figure 7 presents the shrinkage and temperature rebar curtain.

Erection of the F-Level Brenneman/Sunnyside Connection rebar curtains will be from inside the Sunnyside Mine, with the air-side bending stress reinforcement cage, Figure 6, first. Erection can be facilitated by first socketing two #10 horizontal positioning rebar into short, 6-inch to 12-inch deep mortar filled drill holes in the tunnel ribsides 3-1/2 inches from the face of the air-side form. One horizontal positioning bar would be placed near the top of the tunnel and the other near the floor. Two, near rib vertical rebar would then be tied to the horizontal positioning bars. The third step should probably be to fit and tie all the remaining horizontal rebar to the two vertical bars. The final step would be to tie in all the remaining vertical bars. The procedure would be repeated for the shrinkage and temperature rebar curtain, Figure 7, except the water-side form would be placed after building the rebar cage.

The upper two feet of the water-side form would be left open for filling the form. It should be possible to fill almost the entire 8-foot long F-Level Brenneman/Sunnyside bulkhead form through the shrinkage and temperature rebar cage. The slickline will have to be repositioned for final filling of the roof and upper corners of the form as the water-side form is closed.

The concrete pour into the bulkhead should be essentially continuous. As recommended by Troxell, et al (1968, p 174) the fresh concrete surface should not be allowed to set exposed more than 1-1/2 hours before being covered by the next layer of freshly mixed concrete if the concrete mixing, and tunnel, temperature is 70°F. This time delay period can be 3 hours if the concrete mixing and tunnel temperature is 50°F. Larry Perino reports the tunnel temperature to be slightly lower than 50°F. A minimum mixing time of ten minutes is specified. Mixing time effects the 28-day concrete strength (Troxell, et al, 1968, p 171). The strength of the concrete increases for mixing times from 5 to 10 minutes when using multiple cu yd machines. Mixing times in excess of 10 minutes provide no strength increase.

The anticipated critical path bulkhead construction sequence for the F-Level Brenneman/Sunnyside Connection bulkhead is 1) complete removal of tunnel ballast and loosened blast damaged rock on the floor of the tunnel down to solid rock through the bulkhead section, 2) scaling and washing of the roof and walls in the

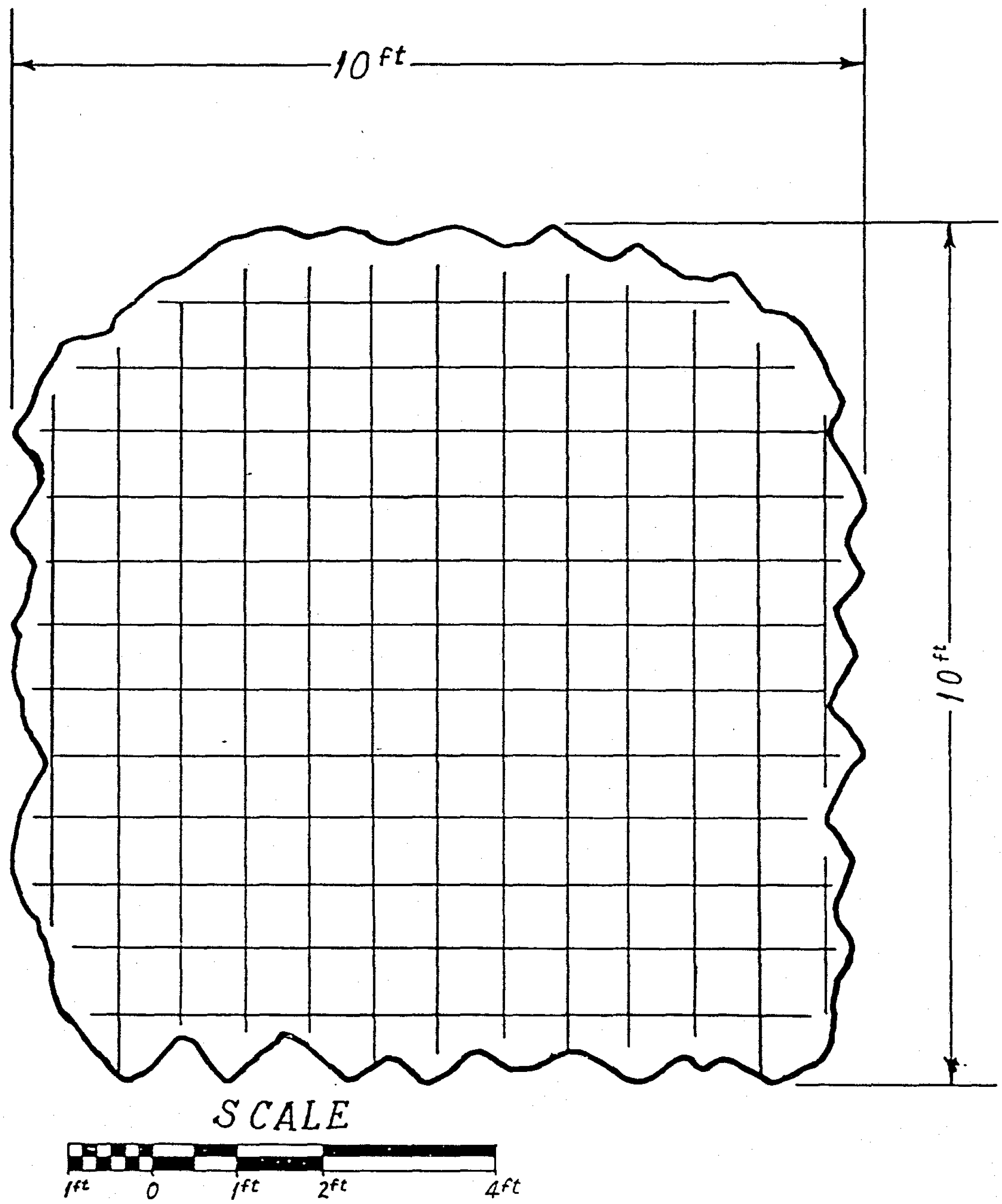

Figure 6. Air-side rebar cage (mat) for flexural reinforcement in the F-Level Brenneman/Sunnyside Connection, #10 bars, 9-in. spacing, 3.5-in. minimum depth of cover.

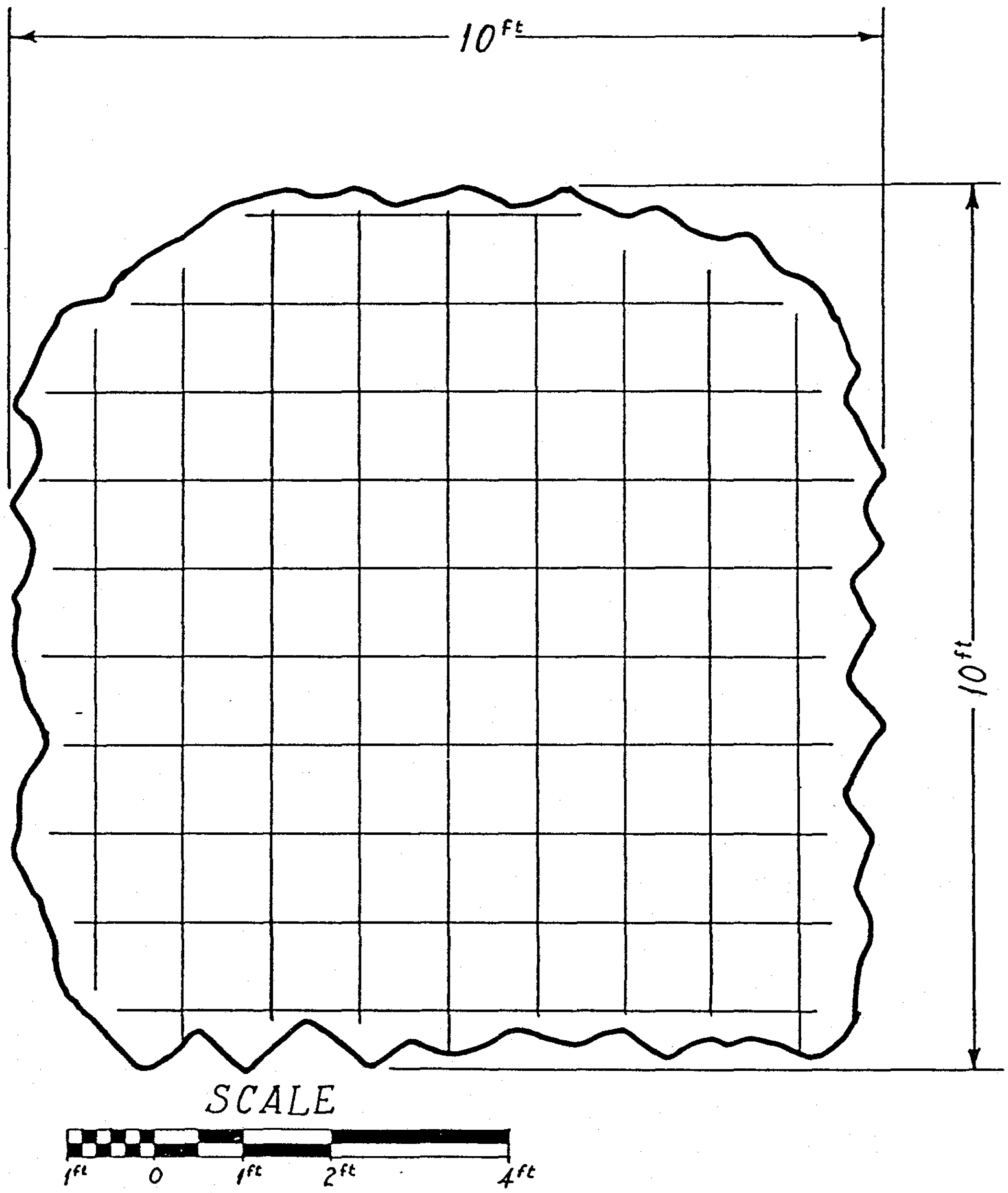

Figure 7. Water-side rebar cage (mat) for temperature and shrinkage control in the F-Level Brenneman/Sunnyside Connection, #6 bars, 12-in. spacing, 3-in. minimum depth of cover.

bulkhead area, 3) construction of the air-side concrete form, 4) erection of the air-side bending stress rebar curtain, 5) erection of the water-side shrinkage and temperature rebar cage with the short plastic guide pipes wired to the rebar cage, 6) construction of the lower approximately 7 feet of the water-side form with the plastic drill guide pipes extending through the form, 7) continuous pumping of concrete through the water-side rebar cage and filling of the form, 8) progressive withdrawal of the slickline as resistance to pumping is encountered, 9) closure of the top of the water-side form and 10) completion of filling of the form.

B-LEVEL BRENNEMAN/SUNNYSIDE CONNECTION BULKHEAD

Access is not now available from what will be the air-side of the maximum 9-foot wide by 9-foot high B-Level bulkhead location in the tunnel connecting the Brenneman and Sunnyside Mines. Access is not anticipated in the future. Therefore, no water pressure measuring pipe is included in this bulkhead. Construction will be facilitated because there is no water flow along the tunnel connecting the Brenneman and the Sunnyside Mines. Therefore, no water diversion pipe will be necessary for the bulkhead isolating the Brenneman Mine from the Sunnyside Mine on the B-Level.

Table 4 presented the recommended bulkhead length, 3 feet, and deep-beam bending stress reinforcement, #6 bars on 12-inch centers, to support the maximum possible 70-foot head. A 2-foot thick bulkhead would provide the required strength to resist the anticipated maximum hydraulic head. However, the 3-foot thickness is recommended because this bulkhead will probably be subject to the most corrosive environment of any of the bulkheads because of its location near the upper open stopes. Six inches of corrosive deterioration could hazard a 2-foot thick bulkhead, but obviously not a 3-foot thick bulkhead. A short 2-foot thick bulkhead will also be difficult to low-pressure grout. Table 5 presented the actual supportable design head for the bulkhead, 80 feet. The design head includes the ACI required 1.4 factor for the actual maximum head and the 0.90 factor for the design tensile strength under one-way deep-beam bending. The mean actual factor of safety for the B-Level Brenneman/Sunnyside Connection bulkhead is 1.77.

Figure 8 presents a schematic of the air-side rebar curtain for the B-Level Brenneman/Sunnyside Connection bulkhead. Figure 9 presents the shrinkage and temperature rebar curtain, which will be nearly identical to the air-side rebar curtain.

Erection of the B-Level Brenneman/Sunnyside Connection rebar curtains will be from inside the Sunnyside Mine, with the air-side bending stress reinforcement cage, Figure 8, first. Erection can be facilitated by first socketing two #6 horizontal positioning rebar into short, 6-inch to 12-inch deep mortar filled drill holes in the tunnel ribsides 3-1/2 inches from the face of the air-side

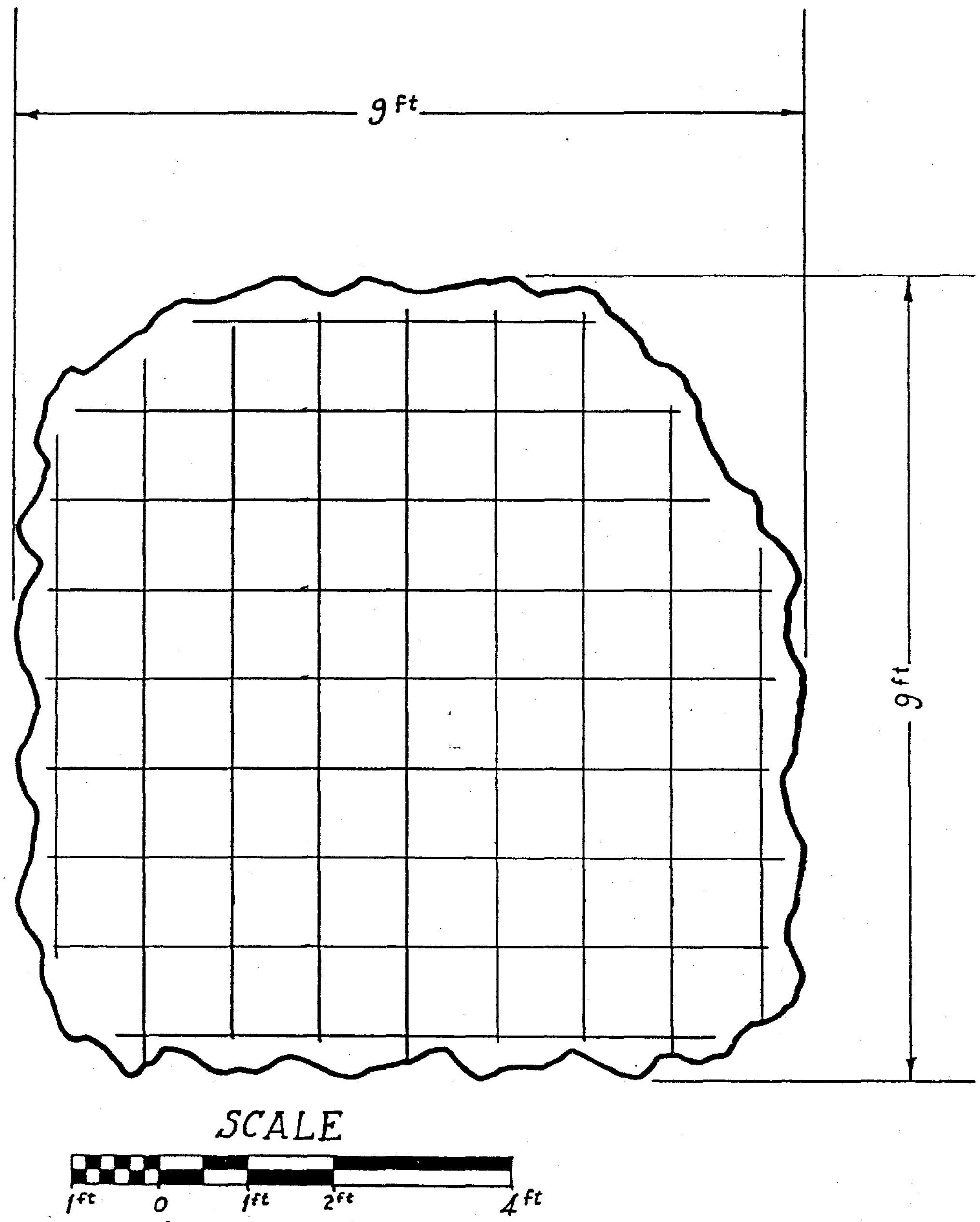

Figure 8. Air-side rebar cage (mat) for flexural reinforcement in the B-Level Brenneman/Sunnyside Connection, #6 bars, 12-in. spacing, 3.5-in. minimum depth of cover.

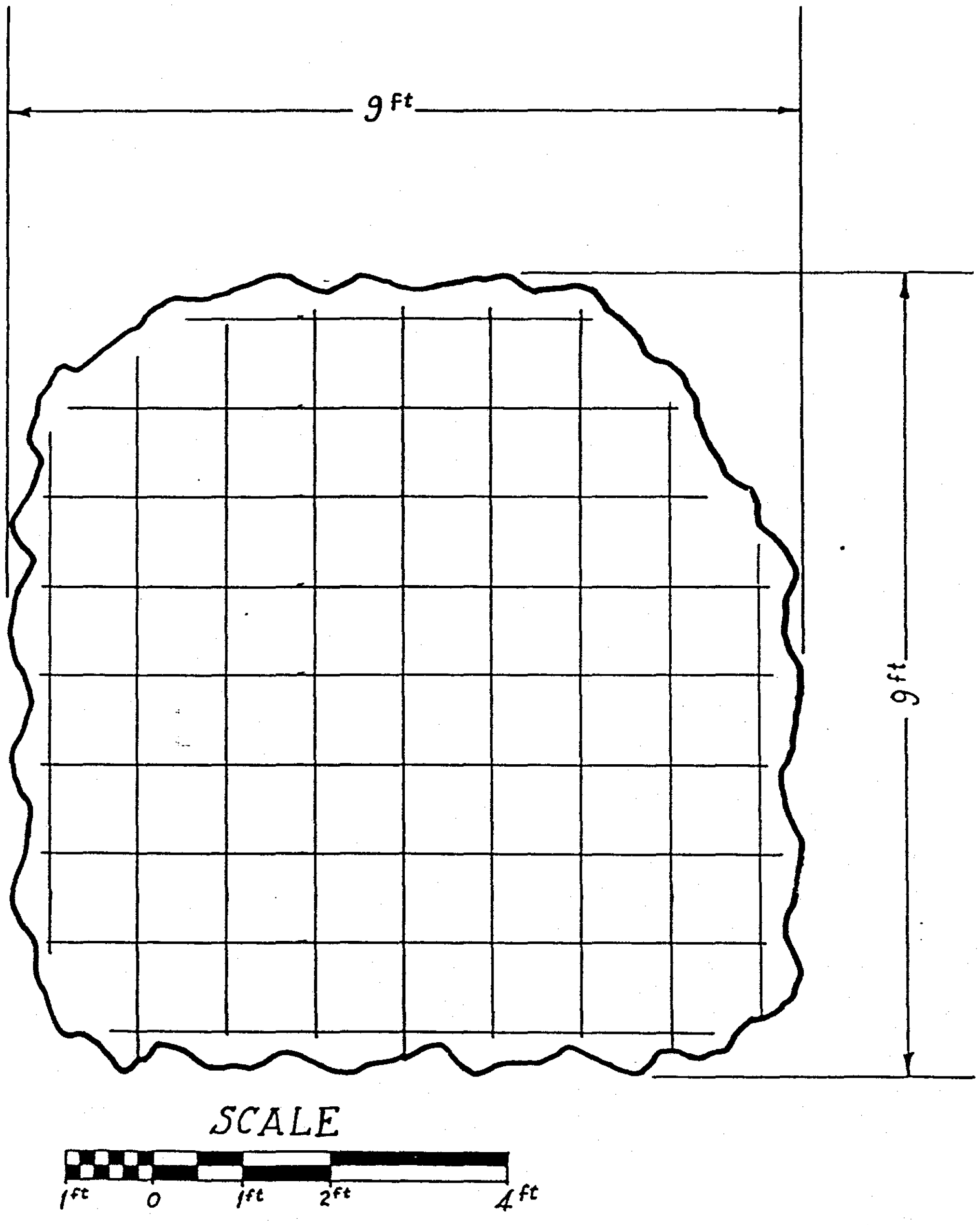

Figure 9. Water-side rebar cage (mat) for temperature and shrinkage control in the B-Level Brenneman/Sunnyside Connection, #6 bars, 12-in. spacing, 3-in. minimum depth of cover.

form. One horizontal positioning bar would be placed near the top of the tunnel and the other near the floor. Two, near rib vertical rebar would then be tied to the horizontal positioning bars. The third step should probably be to fit and tie all the remaining horizontal rebar to the two vertical bars. The final step would be to tie in all the remaining vertical bars. The procedure would be repeated for the shrinkage and temperature rebar curtain, Figure 9, except the water-side form would be placed after building the rebar cage.

The upper two feet of the water-side form would be left open for filling the form. It should be possible to fill the entire 3-foot long B-Level Brenneman/Sunnyside bulkhead form through the shrinkage and temperature rebar cage. The slickline will have to be repositioned for final filling of the roof and upper corners of the form as the water-side form is closed.

The concrete pour into the bulkhead should be essentially continuous. As recommended by Troxell, et al (1968, p 174) the fresh concrete surface should not be allowed to set exposed more than 1-1/2 hours before being covered by the next layer of freshly mixed concrete if the concrete mixing, and tunnel, temperature is 70°F. This time delay period can be 3 hours if the concrete mixing and tunnel temperature is 50°F. A minimum mixing time of ten minutes is specified. Mixing time effects the 28-day concrete strength (Troxell, et al, 1968, p 171). The strength of the concrete increases for mixing times from 5 to 10 minutes when using multiple cu yd machines. Mixing times in excess of 10 minutes provide no strength increase.

The anticipated critical path bulkhead construction sequence for the B-Level Brenneman/Sunnyside Connection bulkhead is 1) complete removal of tunnel ballast and loosened blast damaged rock on the floor of the tunnel down to solid rock through the bulkhead section, 2) scaling and washing of the roof and walls in the bulkhead area, 3) construction of the air-side concrete form, 4) erection of the air-side bending stress rebar curtain, 5) erection of the water-side shrinkage and temperature rebar cage with the short plastic guide pipes wired to the rebar cage, 6) construction of the lower approximately 6 feet of the water-side form, 7) continuous pumping of concrete through the water-side rebar cage and filling of the form, 8) progressive withdrawal of the slickline as resistance to pumping is encountered, 9) closure of the top of the water-side form and 10) completion of filling of the form.

EARTHQUAKE BULKHEAD LOADING PREDICTIONS

The San Juan Mountains are located in the Western Mountain Seismotectonic Province (Lindeburg, 1990, Kirkham and Rogers, 1981). This province covers the Rocky Mountains from Montana to west Texas and Arizona. This province has been designated as a seismic risk zone of "1". The indicated Modified Mercalli earthquake intensities for this province are from V to VI. A

structure in seismic zone "1" would be subject to a design Modified Mercalli intensity earthquake producing a peak acceleration between 0.08 g and 0.15 g (Lindeburg, 1990, p 13). Zone "1" maximum earthquakes could have Richter magnitudes of 4.75, on the low end for "Moderate" earthquakes (Lindeburg, 1990, p 17). Kirkham and Rogers (1981) performed a more detailed study of the earthquake potential for southwestern Colorado and indicate a "maximum credible earthquake" Richter magnitude of 6 to 6.5, on the high end for "Moderate" earthquakes. Algermissen and others (1982) presented a method of assigning a peak acceleration to the "maximum credible earthquake" that has a 90 percent probability of not being exceeded in 250 years. This method, when applied to the available earthquake data for southwestern Colorado, predicts a peak acceleration of 0.12 g at the Sunnyside Mine area. The source for the "maximum credible earthquake" affecting the Sunnyside Mine area is the Ridgeway fault, approximately 25 miles north-northwest of the mine (Knight Piesold & Co., 1988, p 65). The maximum horizontal acceleration component of this "maximum credible earthquake" of 0.087 g directed radially from the focus point. The horizontal earthquake acceleration component is the critical component for bulkheads placed in horizontal tunnels. The Terry Tunnel is the only bulkhead that is roughly aligned radially from the Ridgeway fault source. However, all the bulkheads were conservatively analyzed for earthquake induced acceleration loads directed parallel to the tunnel, and bulkhead, axis.

The mass that can be accelerated against a bulkhead is the water in the tunnel plus the bulkhead itself. The water in the tunnel must be directly facing the bulkhead, i.e. must be within the line of sight of the bulkhead. Water that is impounded by the bulkhead but not directly facing the bulkhead will be accelerated against the rock walls in the direction of acceleration. The ACI earthquake design procedure (ACI 318-89, Section 9.2.3) is directly applicable to deep-beams, which closely approximate a bulkhead. The ACI design procedure for reinforced concrete structures requires a load factor of 1.4 times the calculated earthquake force (E). The earthquake load (E) is added to a factored fluid load (F). However, under earthquake loading the factor for the fluid load force (F) acting on the bulkhead is reduced to 1.05 from the 1.4 factor for long term sustained fluid load design. Apparently the dynamic nature of the earthquake acting on the fluid load has been found in practice not to be as hazardous to reinforced concrete structures as the long term fluid load. Reinforced concrete structures are subject to long term creep when subject to near failure compressive stresses (Troxell, et al, 1968, p 313).

Table 6 presents the ACI earthquake design loading for the "maximum credible earthquake" with a probability of 90 percent over a 250 year period. As can be seen in Table 6, the bulkheads are considerably over designed for earthquake loading. A prime reason for this overdesign is the low height of the bulkheads. Lindeburg (1990) presents a Uniform Building Code (UBC) based base shear (V)

Table 6. Bulkhead evaluation under 0.087 g horizontal acceleration from "maximum credible earthquake"

INPUT: Maximum credible earthquake of magnitude 6.5 on the Ridgeway fault, 25 miles north of the Sunnyside Mine (Knight Piesold & Co., 1988, p 65) Earthquake load is from acceleration of bulkhead plus line-of-sight water impounded behind bulkhead. Reinforced concrete earthquake design from ACI 318-89 Sections 9.2.2 and 9.2.3. Design bulkhead load (U) equal to 1.05 times the fluid load (F) plus 1.4 times the earthquake load (E).

Bulkhead Tunnel Ident.	Length, Line of Sight Water (ft)	E-quake Force (lb/ft)	Bulkhead E-quake Design Force (lb/ft)	Rebar Required (in^2/ft)	Rebar Supplied (in^2/ft)	Factor of Safety
American Tunnel	2486	5580	109100	1.737	2.177	1.26
F-Level Terry Tunnel	1200	2261	42600	1.693	2.177	1.28
F-Level Brenneman/ Sunnyside Connection	30	83	41400	1.009	1.693	1.67
B-Level Brenneman/ Sunnyside Connection	150	2147	4120	0.344	0.440	1.27

method of predicting the earthquake force potentially imposed on the bulkheads. It is interesting that this method predicts a 5820 lb/ft maximum earthquake force acting on the American Tunnel bulkhead, just over 4 percent higher than the ACI predicted 5580 lb/ft maximum earthquake force. The UBC based method includes 1) a seismic zone factor (Z), 2) an importance factor (I), 3) a base shear coefficient (C) based on the period for the structure (T) and a site coefficient (S), 3) an energy absorption coefficient (R_w) and 4) the weight of the accelerated body. The UBC method was not relied upon because it pertains specifically to buildings sitting on soil or rock and not attached to the foundation. The ACI deep-beam analogy is more appropriate.

POTENTIAL IMPACT FROM OUTBYE AMERICAN TUNNEL BULKHEAD

The potential exists for the construction of another bulkhead in the American Tunnel. This bulkhead would be designed to impound the 400 gpm to 500 gpm of water entering the tunnel through the steel set supported permeable fault zone approximately 3000 feet in from the portal (Stock & Walston, 1992, p 40, Figure 10). This fault zone appears to be represented at the ground surface overhead by a stream course and topographic low. A fault zone of significant thickness, over 200 feet, within the tunnel, has less erosion resistance than adjacent unfaulted rock and tends to locally control the surface drainage pattern. The overlying topographic low is 650 feet above the tunnel. This 650-foot height is the probable maximum head that can be applied to a bulkhead in the tunnel downstream of the fault zone. The present ground water flow into the tunnel would, therefore, be reversed and exit at the ground surface at the same location it exited before the American Tunnel intersected and provided a lower resistance flow path. The actual head developed on the bulkhead will probably be less than 650 feet and 290 psi.

If a second American Tunnel bulkhead is constructed downstream from the permeable fault zone the recommended location is the relatively dry tunnel section between 2800 feet and 3000 feet in from the portal. An 11-foot thick reinforced concrete bulkhead would be needed. The design length of bulkhead required to prevent water leakage using low pressure grouting is 7 feet. A 9-foot design length would be required to resist shear in the concrete. A 22-foot design bulkhead length would be required for a plain concrete plug to resist one-way deep-beam bending. The recommended 11-foot long reinforced concrete bulkhead will require #10 bars on 7-inch centers to support the deep-beam tensile bending stress. This design has a factor of safety of 1.03 against design loading including the 1.4 dead or fluid load factor and 0.9 tensile strength reduction factor required by ACI. The actual factor of safety for this bulkhead is 1.61.

The earthquake design load for the maximum approximate 2600-foot line of sight hydraulic load and bulkhead load are 5760

lb/ft and 42590 lb/ft, respectively. The design factor of safety of this bulkhead would be 1.92 against earthquake loading.

This downstream American Tunnel bulkhead should not be subject to the 670 psi leakage pressure from the main American Tunnel bulkhead. Any leakage from the main American Tunnel bulkhead would be diverted up the permeable fault zone, limiting the hydraulic head to a maximum of 290 psi.

The impoundment of water behind this bulkhead would apply the same maximum 290 psi against the downstream face of the main American Tunnel bulkhead. The back pressure on the main American Tunnel bulkhead would balance a portion of the hydraulic head applied to that bulkhead. The shrinkage and temperature rebar in the main American Tunnel bulkhead is capable of supporting a design head of 320 feet of water, 140 psi, applied to its downstream face. This assumes that air is present on the inbye side of the main American Tunnel bulkhead. It is not reasonably possible for the upstream face of the main bulkhead to have no hydraulic head because of the current 930 gpm passing the planned bulkhead location. The minimum probable hydraulic head on the main American Tunnel bulkhead is the 900 feet, 390 psi, below any unanticipated F-Level drainage. Therefore, a reversal of stress direction on the main American Tunnel bulkhead should never occur as the result of constructing a downstream bulkhead.

MATERIAL QUANTITIES

The primary materials required for construction of the individual bulkheads are rebar and concrete. The rebar lengths listed in Table 7 are based on maximum and uniform width and height for the individual tunnels. This assumption should result in considerable excess when pieces are cut to fit the actual tunnel dimension on site. The off cuts will be short and probably of little practical use. The total length and weight of rebar indicated in Table 8 is what will be taken to the individual bulkhead construction sites. The concrete yardage listed in Table 8 is also based on the assumption that the individual sites are the maximum height and width and uniform throughout the length of the bulkheads. The actual concrete yardage required will be less than the indicated because the tunnel will, in general, be shorter and narrower than the maximum dimensions.

The American Tunnel bulkhead will require approximately 100 feet of 12-inch diameter flanged steel pipe. The upstream coffer dam is assumed to be 50 feet upstream from the bulkhead in order not to interfere with bulkhead construction. If a concrete coffer dam is constructed it should be possible to decrease the upstream distance and the required extension pipe length. It was assumed that the downstream pipe will extend 25 feet below the bulkhead to assure bypass water discharge well away from the bulkhead. If it

Table 8. Preliminary Bill of Material, totals

NOTES: 1) #10 rebar 4.303 lb/ft, 1.270-in. diameter, 1.27 sq in. area, 3.5 in. from air-side face, 2) Water-side temperature and shrinkage rebar options, #6 bars on 12-in. centers each way or #4 bars on 6-in. centers each way, 3) #6 rebar 1.502 lb/ft, 0.750-in. diameter, 0.44 sq in. area, 4) #4 rebar 0.688 lb/ft, 0.500 in. diameter, 0.20 sq in. area, 5) temperature and shrinkage rebar minimum 3-in. cover of concrete from water-side face.

Bulkhead Tunnel Ident.	Length Reco-mmended (ft)	Rebar Size/ Spacing (in.)	Rebar Required Length (ft)	Rebar Required (lbs)	Concrete Required (yd^3)
American Tunnel	25	#10 @ 7	<572	<2460	<156
13 x 13 ft	25	#6 @ 12	<338	< 510	
F-Level Terry	8	#10 @ 7	<418	<1800	< 36
Tunnel 11 x 11 ft	8	#6 @ 12	<242	< 370	
F-Level Brenneman/	8	#10 @ 9	<260	<1120	< 30
Sunnyside Connection	8 10 x 10 ft	#6 @ 12	<200	< 300	
B-Level Brenneman/	3	#6 @ 12	<162	< 700	< 9
Sunnyside Connection	3 9 x 9 ft	#6 @ 12	<162	< 250	

NOTES: Single pieces of rebar, individually cut to fit on site. Rebar minimum 3.5 in. from air-side face and 3 in. from water-side face

is decided to use "extra strong, schedule 80" pipe within the bulkhead, it will still be possible to use "standard weight, schedule 40" pipe for the pipe sections upstream and downstream from the bulkhead because these sections cannot be subject to water pressures that may develop within the bulkhead. The total weight of "standard weight, schedule 40" 12-inch diameter steel pipe will be approximately 5000 lbs. If the bulkhead is constructed using "extra strong, schedule 80" pipe the total pipe weight will be approximately 5500 lbs. The pipe is to be in 5-foot lengths weighing approximately 250 lbs for "standard weight, schedule 40" 12-inch diameter steel pipe and approximately 330 lbs for "Extra strong, schedule 80" pipe. The 12-inch diameter gate valve for the downstream face will require a hoisting and positioning arrangement because of its weight.

Forty-six 1/2-inch diameter by 2-inch long headed studs are required for welding to the flanged water bypass pipe.

A blank flange plate with a high pressure cementation cock will be required after closure of the 12-inch valve and verification of the effectiveness of the American tunnel bulkhead. Once the American Tunnel bulkhead functions as designed the downstream extension pipes will be removed and the blank flange plate bolted to the valve. If it is decided to construct the second American Tunnel bulkhead, cement grout should be injected through the flange plate cementation cock to fill the bulkhead pipe to prevent any long term corrosion of the bulkhead pipe. The pipe should be grout filled only if there is no future need to gradually lower the water level in the Sunnyside Mine.

Approximately 40 feet of 1-inch diameter "standard weight, schedule 40" threaded steel pipe will be needed for the water pressure sensing pipes through the American Tunnel and Terry Tunnel bulkheads. This pipe will require couplings, two ball valves, pressure gages and pipe caps. The water pressure sensing pipe through the American Tunnel bulkhead should also be filled with cement grout if it is decided to construct the second American Tunnel bulkhead. The ball valve closed, the pipe cap and pressure gage would be removed, the grout injection hose attached, the valve opened and the pipe filled with cement grout to positively prevent any possibility of long term corrosion of the pipe.

Disposal of the ballast and broken rock excavated from the floor of all the tunnels for the bulkheads and for concrete coffer dam in the case of the American Tunnel, if selected, will require planning in order not to interfere with bulkhead construction.

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APPENDIX A. AMERICAN TUNNEL BULKHEAD DESIGN CALCULATIONS

Notation:

a = compression zone depth(in) min to balance rebar tens
b_w = beam web width(12 in)
c = centroidal distance(in)
d = distance, extreme compression fiber to rebar centroid(in)
E_m = e'quake mass(lb·sec^2/ft)
FS = factor of safety
$\sqrt{f'_c}$ = square root f'_c
f'_s = concrete shear str($2\sqrt{f'_c}$ psi)
g = accel due to gravity (32.2 ft/sec^2)
I = moment of inertia(in^4)
L = beam length or depth(ft)
M = bending moment(ft·lb)
M_u = factored beam moment(ft·lb)
m_c = min cover, form face to rebar surface(in)
T = tensile bending force(lb)
U_α = e'quake required str(lb/ft)
V_n = nominal shear force(lb)
V_u = factored shear force(lb)
W = bulkhead load(lb)
α = e'quake accel(0.087ft/sec^2)
ρ_g = pressure grad(psi/ft)
ϕ = strength reduction factors
0.90 flexure rebar
0.85 shear concrete
0.65 plain concrete flexure

A_s = area of rebar(in^2/ft)
b = beam width(1 in)
C = comp bending force(lb)
D = dead load(lb/ft)
E = e'quake load(lb/ft)
ΣE_m = total e'quake load(lb)
F = fluid load (lb/ft)
f'_c = concrete comp str(psi)
f_{ct} = concrete tensile str(psi)
f_y = rebar yield str(psi)
H = head(1550 ft)
h = tunnel height(ft)
K = $(3.5 - 2.5M_u/d)$
ℓ = tunnel width(ft)
M_n = nominal beam moment(ft·lb)
$M_{u\alpha}$ = e'quake beam moment(ft·lb)
S = section modulus(in^3)
S_ℓ = line-of-sight distance(ft)
U = required str(lb/ft)
V_c = concrete shear str(lb)
V_s = rebar shear str(lb)
v_s = shear stress(psi)
ω = uniform load(lb/ft)
ρ = pressure head(psi)
$\rho_w = A_s/b_w d$
γ_w = water density(62.4PCF)
γ_c = concrete density(151PCF)
σ = flexure stress(psi)

Abbreviations:

str = strength; comp = compressive; grad = gradient;
tens = tension; accel = acceleration; e'quake = earthquake

Load factors (ACI 318, Sec 9.2.2, 9.2.3, 9.2.5)

Static fluid load factor (F) = 1.4; Factor for fluid load under earthquake acceleration (F) = 1.05; Earthquake accelerated load factor (E) = 1.40

Hydraulic pressure gradient:

Low pressure grouting of concrete-rock contact but not rock, gradient allowable = 41 psi/ft (Garrett & Campbell-Pitt, 1958, Chekan, 1985, p 11), with factor of safety of 4

American Tunnel bulkhead, maximum pressure head

$\rho = H\gamma_w/144 = 1550(62.4)/144 = 670$ psi

Required length $\mathbf{L} = \rho/41 = \mathbf{16.3\ ft}$

Pressure gradient with L = 25 ft $\rho_g = \rho/25 = \mathbf{26.8\ psi/ft}$

Concrete shear on American Tunnel perimeter:

$f'_s = 2\sqrt{f'_c} = 2\sqrt{3000} = 110$ psi (ACI 318-89, Sec 11.3.1.1)

$\mathbf{L} = \rho(h)(\ell)/[2(h+\ell)f'_s] = 670(13)(13)/[2(13+13)110] = \mathbf{19.9\ ft}$

$W = \rho h\ell = 670(13)(13)144 = 16310000$ lb

$v_s = W/[2(h+\ell)]L(144) = 16310000/[(25)2(13+13)144] = 87$ psi

$\mathbf{FS} = 110/87 = \mathbf{1.26}$

Plain concrete deep-beam bending stress design, American Tunnel (ACI 318-89, Sec 9.9.2.5, 18.4.1(b) & ACI 318-71, Sec 9.2.1.5)

$\omega = U = 1.4\rho 144 = 1.4(670)144 = 135400$ lb/ft

$M_n = \omega\ell^2/8 = 135400(13^2)/8 = 2860000$ ft·lb

$M_u = M_n/0.65 = 286000/0.65 = 4401000$ ft·lb

$S = I/c = [bL^3/12]/(L/2) = \{1[(L)(12)]^3/12\}/[L(12)/2] = 144L^2/6$

$f'_t = 3\sqrt{f'_c} = 3\sqrt{3000} = 164$ psi

$f'_t = = 164 = \sigma = M_uc/I = M_u/S = 4401000/(144L^2/6)164 = 183000L^2$

$L^2 = 1118$

$\mathbf{L = 33.4\ ft}$ $\therefore$ 25-ft long bulkhead must be reinforced

Reinforced concrete deep-beam bending stress design, American Tunnel (ACI 318-89, Sec 9.3.2.3, Wang & Salmon, 1985)

$C = \phi f'_c b_w a = 0.85(3000)12a = 30600a$

$T = A_s f_y = 60000A_s$

$C = T$; $a = 60000A_s/30600 = 1.961A_s$

$M_n = \omega l^2/8 = 135400(13^2)/8 = 2860000$ ft·lb

$M_u = M_n/\phi = 2860000/0.9 = 3180000$ ft·lb (38130000 in·lb)

$M_u = A_s f_y\ (d-a/2)$; $d = L - m_c = [(25)12 - 3.5] = 296.5$ in

$M_u = 60000A_s(296.5 - 1.961A_s/a) = -58800A_s^2 + 17790000A_s$

$\therefore\ 38130000 = -58800A_s^2 + 17790000A_s$

$58800A_s^2 - 17790000A_s + 38130000 = 0$

$A_s = 2.16$ in^2/ft steel area required

#10 bars on 7-in c-c provides 2.18 in^2/ft steel area

Check for adequacy

Allowable $M_u = -58800A_s^2 + 17790000A_s = 38660000$ in·lb

Design $M_u = 38130000$ in·lb

FS = 38660000/38130000 = 1.01

Critical section shear strength for American Tunnel 25-ft deep beam (bulkhead). Deep beam defined as $l/d < 5$ (ACI 318-89, Sec 11.8.1). Critical section shear $0.15l$ (1.95 ft) from ribside (ACI 318-89, Sec 11.8.5), with #10 bars on 7 in c-c, 2.18 in^2/ft, d = 296.5 in (24.71 ft). Detailed shear strength at critical section (ACI 318-89, Sec 11.8.7)

$l/d = (13)12/[(25)12 - 3.5)] = 0.53 \qquad 0.53 < 5$

$\therefore$ bulkhead is a beep beam for design

$V_c = K(1.9\sqrt{f'_c} + 2500\rho_w V_u d/M_u)b_w d$

$M_n = (\omega l/2)(0.15l) - \omega(0.15l)(0.15l)/2 = 0.06375\omega l^2/2$

$M_n = 0.06375[135400(13^2)/2) = 1459000$ ft·lb

Total load under earthquake acceleration

$\rho = H\gamma_w/144 = 1550(62.4)/144 = 670$ psi

$F = \rho b_w 12 = 670(12)12 = 96500$ lb/ft

$U_\alpha = 1.05F + 1.4E = 1.05(96500) + 1.40(5580)$

$U_\alpha = 101300 + 7800 = 109100$ lb/ft

Earthquake nominal beam bending moment

$M_{n\alpha} = U_\alpha l^2/8 = 109100(13^2)/8 = 2305000$ ft·lb in·lb)

Earthquake factored beam bending moment

$M_{u\alpha} = M_{n\alpha}/0.9 = 2305000/0.9 = 2561000$ft·lb (30730000 in·lb)

Area steel required for earthquake loading

$58800A_s^2 - 17790000A_s + 30730000 = 0$

A_s = 1.74 in^2/ft steel area required

#10 bars on 7-in c-c provides 2.18 in^2/ft steel area

Check for adequacy

Allowable $M_{u\alpha} = -58800A_s^2 + 17790000A_s = 38660000$ in·lb

Design $M_{u\alpha} = 38330000$ in·lb

FS = 38660000/30730000 = **1.26**

APPENDIX B. UNIAXIAL COMPRESSIVE TEST RESULTS

Sample Ident.	Length (in.)	Diam. (in.)	Failure Load (lb)	Failure Stress (psi)	2 x 1 Corrected (psi)	Structural Control of Failure
		American Tunnel				
North Rib	3.878	1.900	41900	14780	14820	Yes
South Rib	3.840	1.901	69800	24590	24620	Minor
Back	3.019	1.899	30000	10590	10260	Yes
		F-Level Terry Tunnel				
South Rib	3.870	1.900	99500	35090	35170	No
Back	3.849	1.900	66300	23380	23420	No
North Rib	3.834	1.900	34000	11990	12000	Minor
		F-Level Brenneman Tunnel				
South Rib	3.750	1.902	47300	16650	16620	Yes
North Rib	3.899	1.900	97100	34250	34360	Minor
Back	3.959	1.901	78900	27800	27940	Minor
		B-Level Brenneman Tunnel				
North Rib	3.858	1.900	52100	18380	18410	Moderate
South Rib	3.864	1.899	46600	16450	16490	Minor

DENSITY MEASUREMENTS

Sample Ident.	Density (PCF)	Sample Ident.	Density (PCF)
F-Level Terry Tunnel		American Tunnel	
South Rib	167.9	North Rib	174.1
Back	169.2	South Rib	170.2
North Rib	159.5	Back	170.0
Mean	165.5	Mean	171.4
S. D.	5.3	S. D.	2.3
F-Level Brenneman Tunnel		B-Level Brenneman Tunnel	
South Rib	162.6	North Rib	172.3
North Rib	165.3	South Rib	171.5
Back	165.3		
Mean	171.9	Mean	164.4
S. D.	0.6	S. D.	1.6

NOTE: S. D. - Standard Deviation